AD NUMBER
AD310377
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM:
AUTHORITY
NRL ltr. 7103/106, 30 Sep 96; NRL ltr. 7103/106, 30 Sep 96

NAVAL RESEARCH LABORATORY REPORT

[redacted]

[redacted]

NAVAL RESEARCH LABORATORY

WASHINGTON 20, D. C.

CONFIDENTIAL

Acc. No. 954 (1)

Navy Department - Office of Research and Inventions

COPY 30 of 30

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

SOUND DIVISION - GENERATION & RECEPTION SECTION

30 August 1945

C-601501

627400

SECTOR SCAN [illegible]
[illegible]

By Dr. H. L. [illegible]

Report S-[illegible]

CONFIDENTIAL

CONFIDENTIAL

CLASSIFICATION CHANGED TO [illegible]
BY AUTHORITY OF [illegible] (Reference Authority)
ON 7-1-46 (DATE)
[illegible] (Signature of Custodian)

* * *

Approved by:

Dr. H. L. Saxton - Head, Generation & Reception Section

Dr. H. C. Hayes,
Superintendent, Sound Division

Rear Adm. A. H. Van Keuren, USN (Ret.)
Director, Naval Research Laboratory

Numbered Pages ...... [illegible]
Plates .... [illegible]
Distribution List .. [illegible]

CONFIDENTIAL

PREFACE

Before this war, scientists at NRL were asking the question "Is it not possible, by methods akin to those of television, to scan a supersonic field in synchronism with the scanning of a cathode-ray tube, and to present on the cathode-ray tube a picture of the contents of the supersonic field?" The answer is "Yes" and the embodyment of the method is the Sector Scan Indicator (SSI).

The detail obtained by television is not approached in SSI because of the long transit time of sound, difficulties ~~which would be~~ encountered in ~~attempting to~~ focusing and many other reasons including lack of cooperation on the part of the subject. Nevertheless, a coarse-grained picture which at least resolved small objects separated in range and at best resolved different parts of the same reflecting object separated in range ~~has been~~ was obtained.

This report tells how SSI functions, presents some of the many uses to which it may be put, and includes photographs and data regarding actual tests.

CONFIDENTIAL

SECRET

56AA 19747

TABLE OF CONTENTS

SECRET

ILLUSTRATIONS

Figures Page

Plates

SECRET

I. FORM OF PRESENTATION AND FUNDAMENTAL THEORY

A. Form of Presentation

1. The Sector Scan Indicator (SSI) is a device for presenting, on the screen of a cathode-ray tube, a picture of the reflecting objects in the field of a supersonic projector. Such objects are displayed as a series of short, bright, horizontal-line segments, with vertical deflection from the bottom proportional to range, and with horizontal deflection from a vertical center line proportional to angular deviation from the axis of the sound beam.

2. Figure 1-a represents the display of an echo at three-fourths maximum range and at 2° to the right of the projector axis. The extent in range corresponds to echo-length.

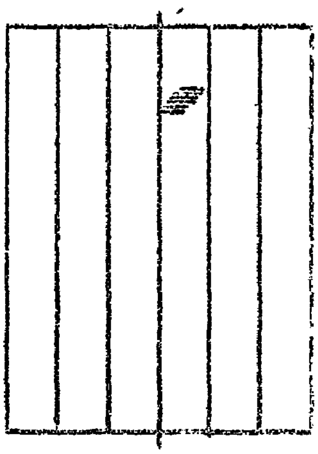


Figure 1-a

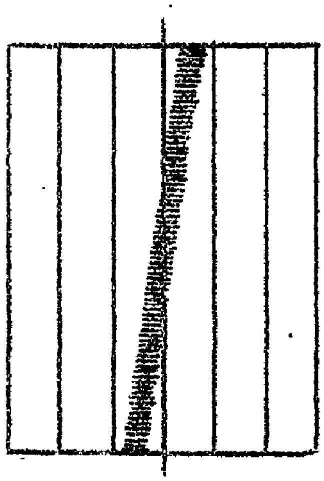


Figure 1-b

3. SSI may be used as well for observing propeller noise. Since prop noise is continuous, the bright line segments recur from the bottom of the screen to the top as in Figure 1-b. The indication shows bearing rate as well as instantaneous bearing. The time required for the vertical sweep in Figure 1-b is four seconds and the bearing change is 4°. This is a bearing rate of 1 degree per second represented by the traversal of one horizontal space during the vertical sweep time. A slower vertical sweep permits reading lower bearing rates more accurately. One space during a vertical sweep may be made to represent $\frac{1}{2}$°/sec., or $\frac{1}{4}$°/sec.

4.   The use of the Sector Scan Indicator in a vertical plane is also feasible. The cathode-ray-tube display is rotated through 90° so that range is shown horizontally and depression above or below the beam vertically. Figure 2 shows a signal arriving from 2° below the axis of the beam, an indication that the projector should be tilted downward 2° in order to center the image. It will be apparent that a tiltable projector is necessary in order to utilize SSI in this form to its fullest advantage.

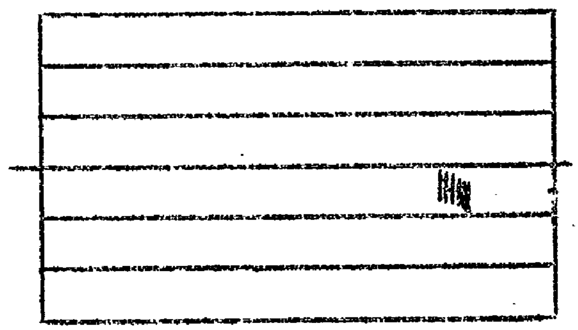


Figure 2

5.   The discrimination between different targets at different ranges is illustrated by the reproduction of actual photographs of SSI displays in Figure 3.

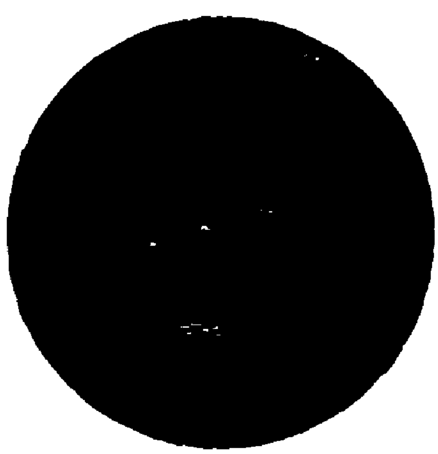


FIG. 3a

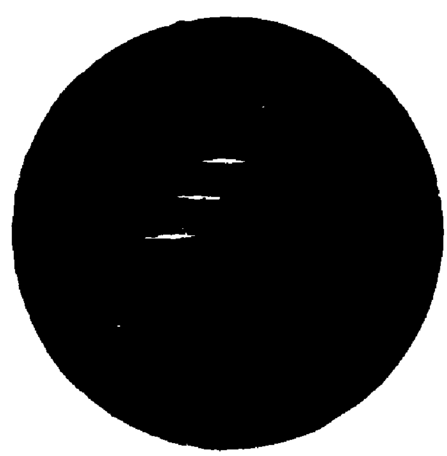


FIG. 3b

SECRET

At 3-a, echoes from a bridge are displayed, three brightened spots representing echoes from three different piers. The indication in the foreground is reverberation. At 3-b, there are displayed three ships, an aircraft carrier, a heavy cruiser, and a light cruiser, lying at anchor in Hampton Roads. The distinctness of each echo is worth noting. The angular separation is shown very definitely.

B. Fundamental Theory

6. SSI requires the use of a projector split electrically along the vertical diameter (or split along the horizontal diameter for use in a vertical plane). When a noise or echo is directed along the beam axis, of the projector, the two halves of the projector should respond alike. If, however, the signal is displaced to the right of the beam axis, it reaches the right half of the projector before it reaches the left half, giving rise to a phase lead in the right-half response ahead of the left-half response. SSI uses this phase difference in the two halves of the projector to produce an indication of the deviation of the source or reflector to the right or to the left of the beam axis.

7. In the SSI display on the screen of a cathode-ray tube, the screen is scanned rapidly from left to right in a succession of horizontal lines, and more slowly from bottom to top in such a manner that the successive horizontal lines are displaced upward, forming a complete rectangular frame. In this rectangular frame, vertical displacement of a brightened spot corresponds to the range of a target from which an echo is received. This correspondence is achieved by starting the scan at the bottom of the screen at the instant a signal is transmitted, by making the vertical sweep linear, and by using the echo to brighten* the spot on the screen at the time of its reception. Thus, since displacement from the bottom of the screen and the range of the reflecting object are both proportional to the time between the transmission of a signal and the reception of an echo, they are proportional to each other.

8. Horizontal displacement from the center represents angular displacement of the reflecting object from the beam axis of the projector. While a complete description of the method of pro-

- -

*In this report the term spot brightening and like phrases "to brighten the spot" refer to the production of a bright spot or a succession of bright line segments on a completely dark background. The phraseology has historical significance and is convenient.

SECRET

ducing proportional horizontal deflection is relegated to Appendix A of this report, a general idea of this method may be obtained from the following description: The signals picked up on the two halves of a split projector (described in paragraph 6) are fed into separate amplifying channels. In these channels the phase of one of the signals is continuously advanced relative to that of the other, 360° in each horizontal sweep across the c-r tube. There result instants of phase coincidence once each sweep, which occur at positions in the sweep depending upon the original relative phase of the incoming signals, and which are made to produce spot brightening on the screen of the cathode-ray tube.

9. SSI thus far has been fixed-tuned to one of three selectable frequencies. The problems involved in producing tuning throughout a wide band considerably exceed in difficulty the same problems in a receiver-amplifier. However, they appear not to be insurmountable and a discussion of methods is given in Appendix A.

II. USES OF SSI IN A/S WARFARE

A. Uses with Searchlight Projector

10. In the attack, there is probably no other type of beam so effective as the trainable and tiltable searchlight beam in maintaining contact with the target and in playing a part in providing information concerning the location of the target for transmission to other related equipment. The use of one SSI to indicate azimuthal centering to the "train" operator and of another SSI to indicate depression centering to the "tilt" operator, enables these two operators to work independently so long as each performs his function properly. Tests described in Appendix II have demonstrated that a team composed of two operators can maintain contact with the target in spite of whatever maneuvers it may execute.

11. The consoles for two operators may be very simple, as illustrated in Figure 4, where the two consoles are shown side

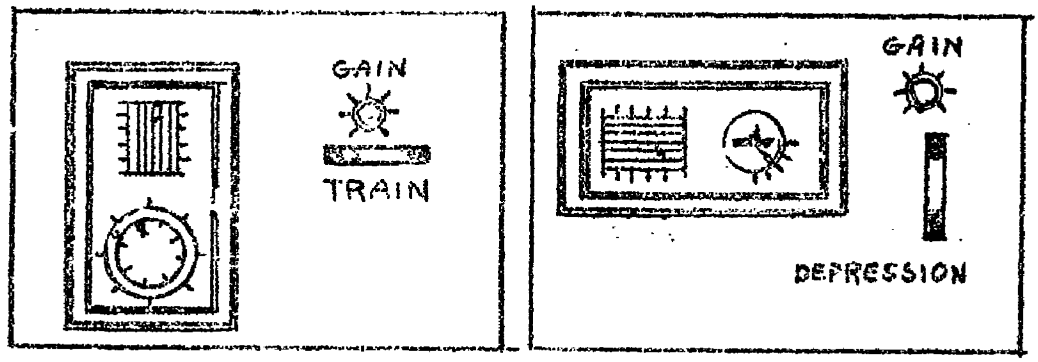


Figure 4

by side. The "train" operator sits before the console shown at the left. The indicator dial shows him the bearing deviation of any target which is picked up, the finger-tip train control enables him to keep the image centered on the cathode-ray tube, while the gain control enables him to adjust the SSI gain for optimum contrast in the image. He is assisted in identifying echoes by the usual audible reproduction. The controls of the receiver amplifier should be within his reach although adjusted preferably by the operator of the range recorder when the latter is at his station. At times coaching of a train operator by the recorder operator and vice versa may prove helpful.

SECRET

12. The tilt operator takes his station only after a contact has been established. At the start of the attack no tilt should be required but as the range is closed, and particularly in running just ahead of or over the target, the projector will have to be tilted to maintain contact. The tilt operator functions only in controlling the tilt and in adjusting the gain of the tilt SSI for optimum contrast in the image.

13. The information obtained by the train operator includes the aspect of the target, while the tilt operator should be able to determine the depth of the target sufficiently soon in the attack. These problems are so important that sections II-D and II-F are devoted entirely to them.

14. The ultimate design (if there is any ultimate) of sonar equipment for the attack must include an attack director. The logical culmination of development is a combination of an attack director and SSI closely interdependent. The SSI, for its part, may be an important factor in obtaining precise preliminary information for feeding the attack director. This information may include target bearing, target bearing rate, range, range rate, target aspect, and target depth. Subsequently, after the problem has been automatically set up in the attack director from sonar information fed to it, the attack director may feed into the projector incremental bearing and depression, as derived from a problem generator, thereby taking over and carrying out automatically the training and tilting of the projector. The train operator may then use any further indication of bearing deviation to correct the training of the projector, thereby correcting the problem setup automatically, while the tilt operator may use the indication of depression deviation to correct the projector depression and thereby the problem setup.

15. Obtaining range and range rate with SSI involves the use of a range gate controlled incrementally by the range generator of the attack director. This gate permits a relatively short extent of normal range, say from 600 yards to 1000 yards, to be selected and expanded to fill the whole screen (see Figure 5). If the generated range is correct, its control of the gate keeps the target vertically centered on the screen. If the echo starts to drift off center vertically, the operator superimposes a correction in the generated range, which in turn tends to correct the

SECRET

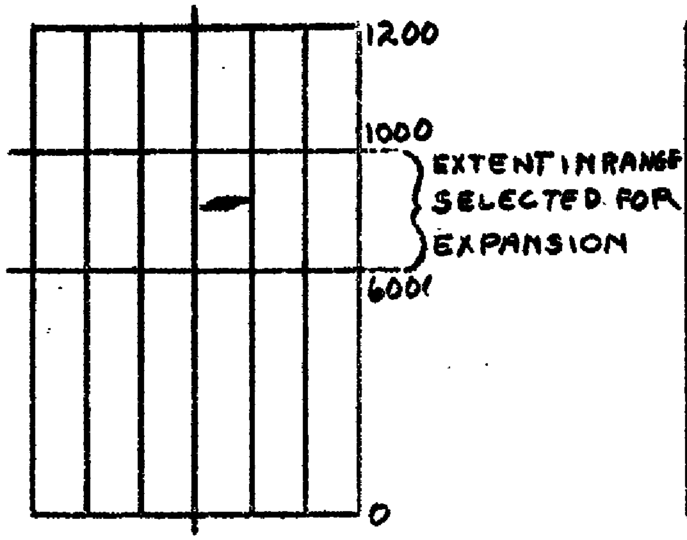


Figure 5-a
Normal Range Scan

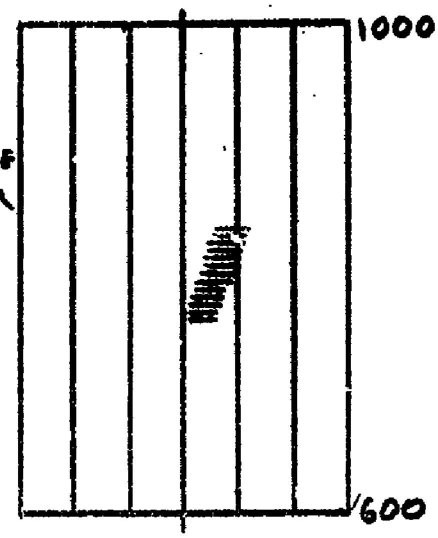


Figure 5-b
Expanded Range Scan

generated range rate. Figure 5-a shows the display obtained from an echo received from a target at about 800 yards range, the whole display covering from zero to 1200 yards range. A certain section of this range from 600 yards to 1000 yards, as indicated by the rectangle superimposed over the display is to be selected by the range gate and expanded to fill the whole screen as shown in Figure 5-b where 600 yards is the range at the bottom of the screen, 1000 yards is the range at the top, and the range of 800 yards which is the generated range comes on center. In this case the center of the echo is slightly above center indicating that the generated range is too short. Therefore the operator should insert an adjustment which brings the spot to center (so that the scale now represents 625 yards to 1025 yards and the center line 825 yards) by directly correcting the generated range. Further discussion of this type of display will be given in Section D under Aspect Indication.

B. Use with Sword

16. The Sword is a projector which produces a fan-shaped beam, broad in azimuth, but extremely sharp in depression angle. The azimuth beam width eliminates the necessity for training the Sword, and tilting only is required. The sharpness of the angle in the vertical plane permits determination of the depression with extreme accuracy. In this determination SSI may play an

important role. In general the deflection sensitivity of SSI is inversely proportional to the beam width in the plane to which it is applied. When used with the Sword, full scale deflection should represent about two degrees and the deflection sensitivity near center may be further enhanced, if desired, by the method of phase difference expansion described in II-G. Thus, if stabilizing gear of sufficient accuracy is available, and if the direction from which echoes return is not subject to fluctuations which introduce comparatively large errors, great accuracy is to be anticipated with this combination. A factor which adversely affects the operation of SSI is the presence of echoes returning by paths other than direct. Such extraneous paths are most likely to be provided in a plane vertical with the direct path. Therefore, if the reception angle in this plane can be kept narrow the undesired interference is more likely to be eliminated.

17. An additional projector must be used with the Sword in order to permit the determination of azimuth. Such a projector could be, for example, another Sword rotated through 90° to give a fan-shaped beam narrow in azimuth. Another combination which has favorable possibilities is the use of the Sword with QH Scanning Sonar. In either combination, the SSI affords a sensitive indication of bearing deviation.

C. Use with QH Scanning Sonar

18. The QH gear gives a presentation on a cathode-ray tube which is a plan position indication, "PPI". While this type of presentation has the advantage of covering all directions simultaneously, there is less detail than is given by the SSI, which covers only a small sector. The QH indicates a target as occupying a whole beam width, which so far has been about 15° or greater. SSI gives an indication occupying not over 2° of beam width unless the target subtends a larger angle. When obtaining an indication of a target at short range with QH, the angular sensitivity is poor because the radial distance from the center is small; consequently angular displacement does not produce much linear displacement. The normal type of presentation of SSI gives as good angular sensitivity at short range as at long. Finally, the SSI registers 400 times per second during the reception of an echo, whereas the QH registers only 30 times per second. While the QH is giving one line the SSI gives 13. Consequently the SSI is intrinsically better able to indicate aspect as discussed in Section II-D, under "Aspect Indication". The advantages of SSI over QH in accuracy and detail are enumerated in order to justify the use of the former with the latter, each supplementing the other. In search, a QH would be expected to be the more effective. In attack, the SSI should give more information and greater accuracy, and it should function better with an attack director.

19. The QH gear is normally provided with a listening channel directed in azimuth to cover a desired sector, and this listening channel is of great assistance in identifying suspected echoes because echo quality becomes observable in it. The SSI may be directed into the same sector and trained in the same manner as the receiver channel. Thus whenever an indication on the QH is suspected of being an echo, corroboration may be obtainable by directing the receiving channel and the SSI into the sector from which the suspected echo arrives. If an attack follows, the SSI may prove of primary importance.

D. Aspect Indication

20. Since SSI is a proportional deflection device, a succession of echoes from different directions and ranges register independently and in their correct angular positions and ranges provided that the outgoing signal is short enough so that the successive echoes do not suffer much overlap. For example, in Figure 6-a, a sound beam is shown in relation to a shore line. The shaded portion

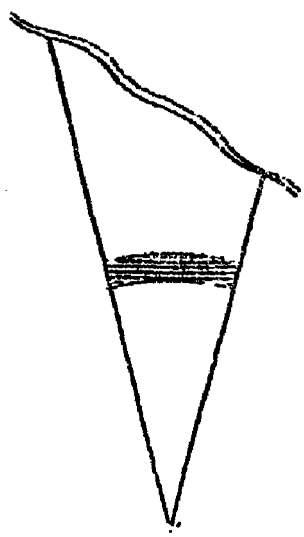


Figure 6-a

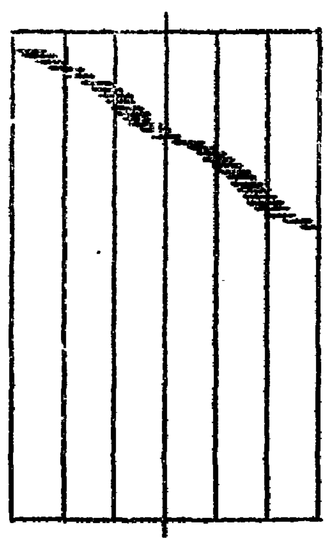


Figure 6-b

SECRET

of the beam represents the extension in range of a signal 10 milliseconds long. This pulse is travelling toward the shoreline and will shortly reach that portion of the shoreline at the right of the beam. Whatever reflection is obtained from this portion of the shoreline will be the first reflection to be received and will register on the SSI display at the extreme right of the screen. Thereafter reflections will be received from different angular positions progressing to the left and in every case the correct angular position will be shown in the SSI display. Consequently a display similar to Figure 6-b will be obtained. This type of display may be termed aspect indication.

21. Another manifestation of aspect indication occurs in echoes from wakes. Figure 7-a is a reproduction of a photograph of an SSI display in the wake of a surface vessel. The scattered line

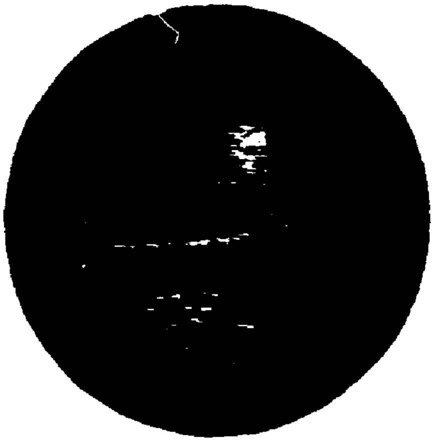


FIG. 7a

FIG. 7b

segments at the bottom of the Figure are reverberations. (The direction from which these are received is, of course, indicated.) A short distance above the reverberations the wake echo may be seen extending from left to right as the range increases. This clearly shows that the nearest approach of the track of the ship which produced the wake is at the left of the screen. At the top of the display is shown propeller noise received from the ship which produced the wake. This prop noise shows in the display only at long range, because the operation of time variable gain reduces the receiving sensitivity to all signals at the instant of transmission and gradually restores this sensitivity, thereby permitting response to relatively strong wake echoes at short range while the sensitivity is still too low to respond to prop noise, but also permitting response to prop noise at a later time when greater sensitivity has been restored. The presence of prop noise at a particular angle identifies the angular position of the ship. It may

be deduced from this photograph that the ship is moving toward the right, and that the range is opening. Figure 7-b is a photograph of another wake left by a ship progressing from right to left and opening its range.

22. More recently the same sort of aspect indication has been obtained from a submerged submarine under conditions where no wake echo was received. Figure 8 illustrates echoes from an elongated submerged target. In 8-a, the nearer portion of the

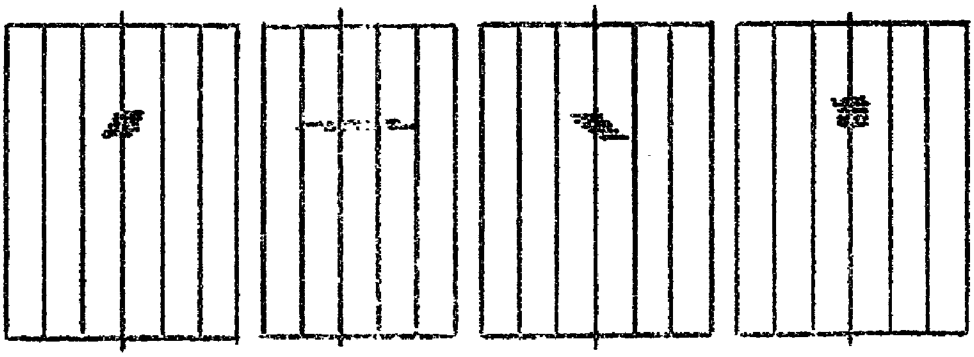


Figure 8-a Figure 8-b Figure 8-c Figure 8-d

target is toward the left. In 8-b, all parts of the target are at the same range. In 8-c, the nearer part of the target is toward the right, and in 8-d, the successive echoes all come from the same direction, which fact clearly indicates that the axis of the target is along the sound beam. Some idea of the scope of SSI in indicating aspect may be gained from Figures 6, 7, and 8. Logical extension of this application will be considered.

23. In order for the target to be shown in true aspect, which can readily be measured, it is essential that the vertical and horizontal scales of distance be the same. The meaning of this statement is made clear by an examination of Figures 9. At 9-a, there is shown a sound beam with a target in it. The extension in range of this target is represented by ΔR. The extension in width is represented by ΔW. It is essential that the same proportions be obtained on the screen of the cathode-ray tube as exist in the sound field. For the normal SSI scan the require-

SECRET

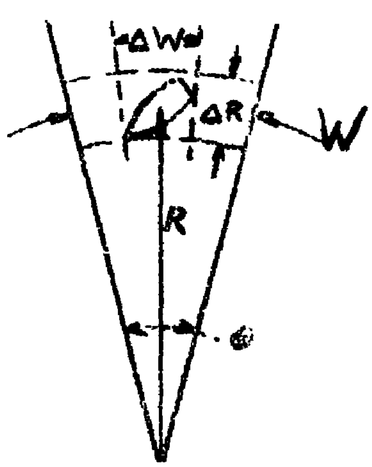


Figure 9-a

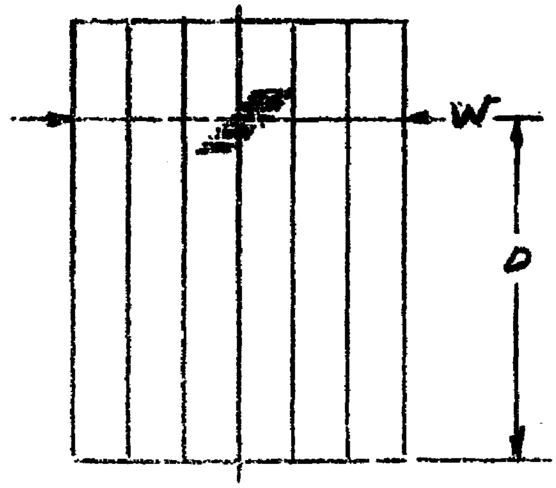


Figure 9-b

ment is fulfilled if the width of the scan is to the distance of the image from the bottom of the presentation as the width of the sound beam at the range R is to that range. Referring to Figure 9-a and 9-b, this mathematical relationship is

$$\frac{w}{D} = \frac{W}{R} = \theta \qquad (1)$$

This relationship is readily satisfied by adjusting the vertical and horizontal gains. w can be fixed once and for all. The rate of sweeping vertically can be adjusted by a control knob until the image comes at a distance d from the bottom of the screen, as indicated by a reference mark, thereby satisfying equation (1).

24. Assuming that the condition of paragraph 23 has been satisfied, and that the true aspect appears on the screen, a means for transmitting this information is illustrated in Figure 10. Here again, the presentation is shown. In addition, the angle between the projector bearing and the course of the submarine is indicated by the symbol "A". A translucent dial on which are engraved a number of parallel vertical lines is placed over the display. This may be rotated by means of a knob to the position illustrated, in which the lines are parallel to the direction of the trace. This rotation is the angle which must be added to the direction in which the projector is trained to give the course of the target. The operation of addition may be accomplished automatically by having a differential synchro generator geared to the cursor in one-to-one ratio, and by feeding into it electrically the true bearing of the projector. Its output of target course can be transmitted to indicators anywhere in the ship. In order to transmit this information correctly the sound operator must maintain two adjustments,

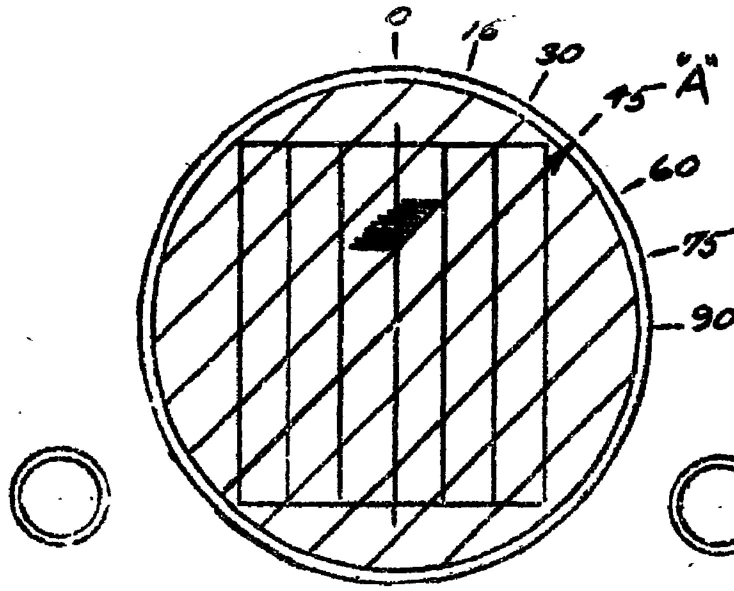


Figure 10

namely vertical sweep rate for positioning the image vertically, for which adjustment the second knob in Figure 10 is provided, and cursor rotation for alignment with the image.

25. The indication when measuring aspect by the method described in the preceding paragraphs suffers from the fact that the width of the scan has to be cut down to very small proportions relative to the length. This difficulty may be overcome by depicting on the screen only a relatively short extension in range starting at, say 200 yards less range than the target and ending 200 yards beyond the target. The type of sweep which is required, then, is a sweep which starts at some time after the signal is sent out. The displacement of the spot vertically plotted against range is shown in Figure 11. With this

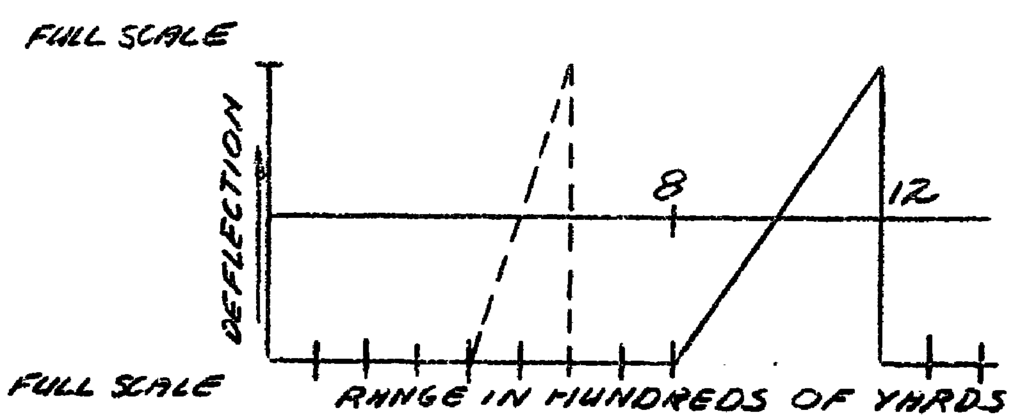


Figure 11

SECRET

type of sweep the relation which has to be satisfied is

$$\frac{l}{w} = \frac{R_2 - R_1}{R\theta}, \qquad (2)$$

in which l and w are respectively the vertical and horizontal dimensions of the SSI frame, θ is the angular width of the sound beam which is scanned by SSI, R is the range which is to be centered in the image, R_1 and R_2 are the ranges corresponding to the bottom and top of the image. In order that this relationship be satisfied for all ranges with l and w fixed, it is necessary that $\frac{R_2 - R_1}{R}$ be constant. That is, the extent of range must be proportional to range, or the rate of sweeping vertically from the bottom to the top of the screen of the cathode-ray tube must be inversely proportional to range. Consequently, the electronic means provided for producing this sweep must increase the speed of sweep at shorter ranges as shown in Figure 11 by the dotted line for shorter range.

26. It has previously been mentioned (paragraph 15) that a display somewhat like the one just described may receive its positioning in range from an attack director, except for adjustments to be added by the sound operator, which adjustments automatically correct the generated range rate. The two functions may be combined and the same display which serves for correcting range rate may be used to show aspect. Note in Figure 5, page 11, how the spreading out of the vertical scale brings out the true aspect of the target.

27. The true sector scan deserves mentioning under the heading of aspect indication. A true sector scan is one which is shaped like the sound field and represents all objects in the field in their correct relative positions. This type of display therefore shows true aspect. It is a crowded type of display for ranges far short of the maximum range depicted, and for this reason is not so well adapted to uses such as fire control where a high degree of accuracy is required. However, it does have possibilities, particularly in navigation. In the section on navigation this method of display will be given further attention.

E. Use with ASAP

28. The AntiSubmarine Attack Plotter (ASAP) is a device which shows a true navigational plot of the courses of own ship and target on the same cathode-ray tube. A spot is made to traverse a course representative of own ship's course. At each ping this spot is brightened and then sweeps out radially from own ship's position in the direction in which the projector is pointed, being

brightened again when an echo is received to indicate the position of the target in the navigational plot. The persistence of the screen is made so long that a number of registrations remain observable simultaneously, thereby enabling the visualization of the tracks as well as the positions of own ship and target. If the projector is trained on the target, the location of the target is correctly depicted, otherwise not. By supplanting the radial scan along a line by a true sector scan (see paragraph 27) with its apex at own ship's position, the indications can be made correct regardless of the precision in training the projector. Even without the addition of this type of sweep, ASAP operation would be improved if SSI were used (preferably with an attack director), to maintain the projector beam on the center of the target.

F. Determination of Depth

29. The simplest use of SSI for the determination of depth is that of centering the projector beam on the target. The depression angle of the projector can be fed into a computer which also uses slant range and bathythermographic data in its computation of depth. This device should preferably be in the form of a recorder in order that instantaneous indications of depth may be averaged out by eye in reading the recorder trace.

30. When the depression angle is changing rapidly, as during an approach, it may be difficult for the depression operator to keep the image centered since he cannot always anticipate the amount of depression increment required from one echo to the next. This difficulty is obviated by the use of an attack director to provide aided tracking, with the sound operator adding only the necessary corrections.

31. In order to determine the depth of a target to within ± 25 feet at a range of 1000 yards, a depression accuracy of $\pm \frac{1}{2}^{\circ}$ is required. The SSI can attain this degree of accuracy with ease provided that the echo does not return from varying directions over multiple paths. Unfortunately, the echo nearly always returns over a minimum of two paths, namely the direct and the one involving a surface reflection. If this is the only cause of the relatively large fluctuations which have actually been observed, the correction of the difficulty would appear to be the placement of the interfering echo on a null point of the projector beam pattern by selection of a proper tilt. This would in general place the image of the desired echo off center by a variable amount depending upon tilt, but a means for taking this offset into account is available since proportional deflection makes readings off center

SECRET

feasible. Operation with the surface reflection on a response null point is illustrated in Figure 12. Other means for reducing the

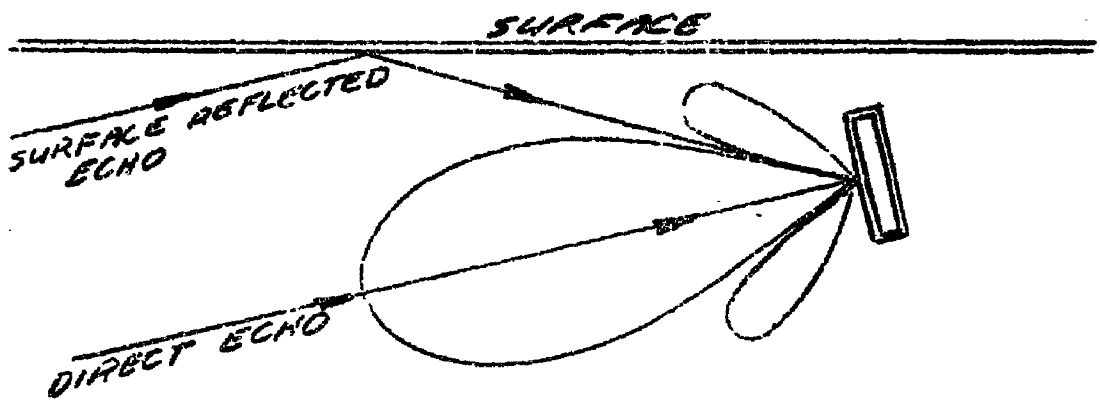


Figure 12

effect of the surface-reflected echo are the use of a projector having a larger vertical dimension for each receiving channel and the use of higher frequency. In either case the objective is the sharpening of the beam pattern.

32. It is now known that the depth of a target can be determined at some range with an error not exceeding ± 25 feet. It is not known whether this range can in all cases be made great enough to permit using the information in the attack, but experimental work is being prosecuted in order to provide the answers.

G. Phase Difference Expansion

33. There is a definite relationship in SSI between the deviation of the image from center and the phase difference fed into the two channels. When the phases differ by 180° the image appears at the edge of the frame. All deflections are in the same proportion to phase difference, which is the meaning of proportional deflection. It is possible to expand the scale in the central cathode-ray-tube display by using a larger c-r tube. When this is done the individual brightened-line segments are likewise expanded in the same proportion and it is doubtful if any gain in sensitivity results in going beyond a 5" diameter cathode-ray tube. However, if the phase difference between the incoming signals is expanded before being fed into the SSI, an increase in sensitivity results. A method of expanding small phase-angle differences is to invert the signal in channel A

SECRET

and to add part of this inverted signal to the signal in channel B, and at the same time to invert the signal in channel B and add part of this inverted signal to the signal in channel A. The Vector diagram in Figure 13-a illustrates the effect. Figure 13-b shows

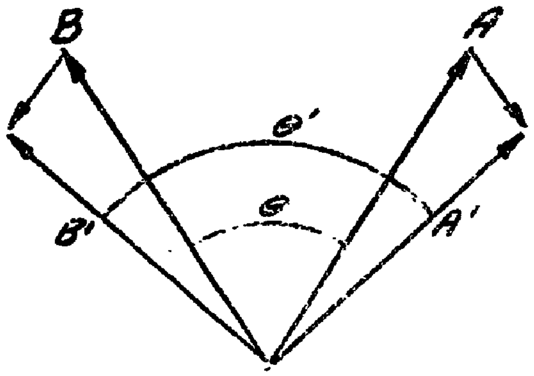


Figure 13-a

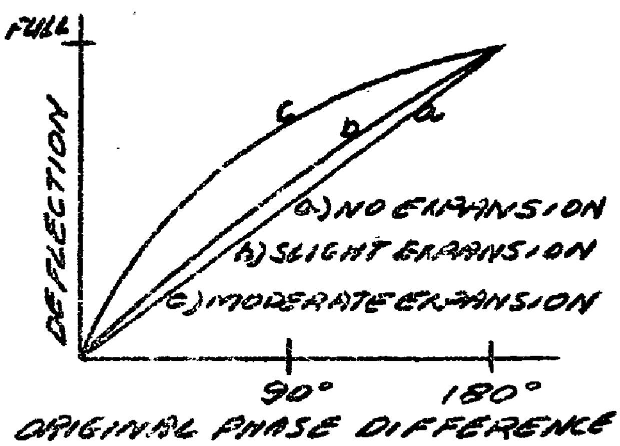


Figure 13-b

various curves of distorted deflection plotted against original phase difference. Expansion of the central portion of the scale of SSI of two to three fold seems to be feasible. Early experimental confirmation is planned.

H. Spotting

34. Spotting is the determination of the position in which the projectile pattern strikes relative to the target. If a pilot projectile is deliberately made to fall short of the pattern center by a known amount, and it can be spotted relative to the target, the fire control corrections can be deduced. Methods of designing such a pilot projectile to enable echo ranging from it are being studied. For example, the emission by the pilot charge of a bubble screen from which echoes can be obtained is receiving attention. The SSI is peculiarly adapted to showing two targets such as a submarine and a pilot projectile on the same screen in their correct relative positions provided that their ranges are different. This last provision necessitates deliberately firing the pilot projectile short in range. The display should be one which shows extension in range from bottom to top and angle from left to right. The sweep should be delayed as previously described

in paragraphs 15 and 26 until the echo range is just short of the pilot projectile. Suppose that the pilot projectile is deliberately fired fifty yards short of the target. Then on the screen of the cathode-ray tube there can be a position as at A in Figure 14 at which the target is held by means of aided tracking and there will be a position B shown in the same Figure at which the pilot projectile should appear. If however, the pilot projectile image actually appears at C in the Figure the error in range and bearing can be

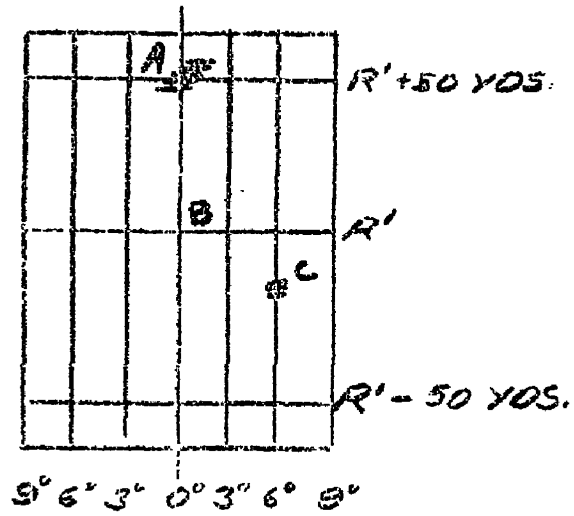


Figure 14

read and called out (as 25 yards short - 6° right, in Figure 14), and this information may also be fed directly to the fire control officer.

SECRET

III. USES OF SSI IN PRO-SUBMARINE PROGRAM

A. Bearing Indication

35. The principal use of SSI in submarines is for training accurately on the propellers of a target, using the SSI indication of propeller noise. A sketch illustrating the nature of this indication is given in Figure 1-b, page 5, except that in that case the projector was not trained to keep the indication centered. For this use the SSI circuits are arranged to complete one frame from bottom to top and then automatically to snap back to the bottom of the screen and start over again. The persistence of the screen is such that the bottom portion of a preceding frame has about faded out at the start of a new frame.

36. The form of the display is shown better in Figure 15-a and 15-b, which is a reproduction of photographs taken in the S20 installation. 15-a shows a centered trace. 15-b illustrates the

FIG. 15a

Figure 15-a

FIG. 15b

Figure 15-b

effect on the display of training the projector across the target and back again.

37. The deflection sensitivity of SSI is related in a definite manner to the geometrical arrangement and dimensions of the two halves of the projector, and to the frequency used. With a 13" diameter projector (crystal diameter), operating at 25 kc, deflection to the extreme right or left indicates a bearing deviation of $\pm 12^{\circ}$. With the use of a projector of twice the diameter, which is contemplated, deflections to the edge of the frame would represent

±6° bearing deviation at the same frequency. Even with the former sensitivity, carefully controlled tests indicate the possibility of centering, with an average deviation from simultaneous periscope readings plus correction for parallax, of 12 minutes. With a larger projector, with an improved geometrical division of the projector into two sections for reception, and with a phase difference expander as auxiliary equipment, it appears that errors introduced by the SSI can be made completely negligible. Of course, errors in the direction of arrival of the noise are beyond control and should prove limiting factors in ultimate accuracy.

B. Use with TDC

38. The objective of determining target bearing with extreme accuracy is to feed the TDC, especially when the submarine is submerged and cannot safely expose its periscope. The feed to the TDC receiver (embodied in the Mark IV) is at 1 and 36 speeds from the projector shaft. The indication is given at the TDC receiver on ring dials where it is compared with generated bearing corrected for parallax. Any failure of the generated values to follow the observed values can be used by the TDC operator in introducing corrections into the TDC problem setup.

39. The TDC Mark IV has an incremental bearing output which can be fed into the training system of the projector, thereby providing aided tracking. When this feature is made use of, and when the problem is correctly set up, the sound operator need not train, save to insert corrections.

40. With the system thus far described there is one missing link, namely automatic correction of problem setup. This can ultimately be achieved by the provision of an error voltage output from the SSI for use in automatic correction of generated bearing and bearing rate in the TDC.

C. Use with Triangulation Listening Ranging

41. Since the SSI is intrinsically a device which can measure angles with great accuracy, the possibility of obtaining ranges by triangulation is enhanced by its use. Two schemes of triangulation, each possessing certain inherent advantages and disadvantages are under consideration. These are (a) triangulation in a horizontal plane using the distance between projectors placed well forward and well aft on the submarine as a base line (b) triangulation in

a vertical plane using the vertical distance from the surface to the single projector as a base line.

42. The method of horizontal triangulation is illustrated in the sketch of Figure 16, which shows in perspective a triangle formed by the target's propellers and the two projectors on the

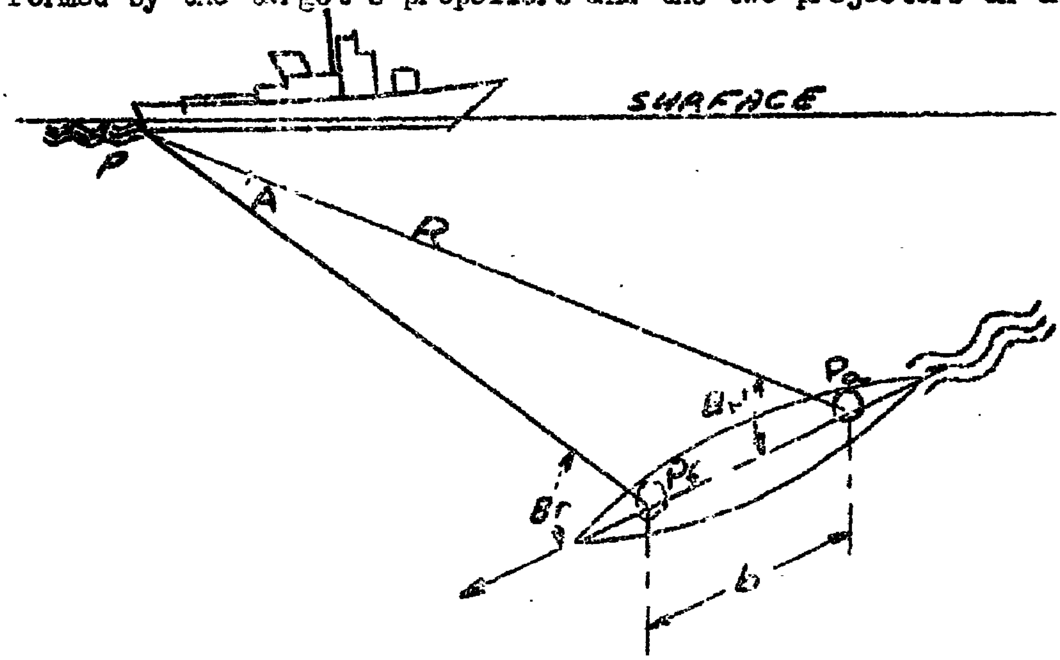


Figure 16

submarine used for the triangulation. The forward projector is more likely to be used for measuring bearing B_r. The aft projector measures a different bearing B_r'. The difference between these two angles is the angle A subtended by the two projectors at the propellers of the target. The range from either projector is approximately R. Now the relation which has to be satisfied in this geometrical arrangement is the following:

$$\frac{\sin A}{b} = \frac{\sin B_r}{R}. \tag{3}$$

This may be solved by a suitable computer since everything in the equation except R is known or obtainable from the bearings at the two projectors. Horizontal triangulation has been carried out successfully in the "TLR" at ranges up to about 2500 yards on the beam of own ship. At small angles off the bow or stern the base line is so greatly reduced that operation is possible only at much shorter ranges. "TLR" functions without the benefit of SSI. Also, it lacks aided tracking by TDC in angle and range. It is believed that the addition of these features, together with the use of error voltages to correct the problem setup would result in

SECRET

a substantial increase in accuracy in this method of obtaining ranges. The proposed scheme for training the projectors is to have the forward projector provided with aided tracking from the TDC and to provide an angular differential between the two projectors which comes from generated range. Errors in the differential may be observed independently of errors in bearing by switching from one projector to the other for SSI and observing whether the indication shifts on the screen without reference to whether it is centered. Also an independent error voltage may be obtained for correcting the generated range and range rate. The advantages of this method of triangulation over that in a vertical plane are its independence from depth of the submarine, from temperature gradients, and from roll and pitch of the ship.

43. Vertical triangulation is now receiving preliminary tests. This method requires a tiltable projector and means for determining precisely the elevation of the target. It requires the use of stabilization to compensate for roll and pitch of the ship, and of computers which make an allowance for temperature gradients as determined from bathythermograph readings previously obtained. The advantages of this system are a longer base line obtainable by deep submergence of the submarine, and the lack of dependence of the length of base line on the relative bearing of target.

44. Figure 17 illustrates vertical triangulation. As will be seen by reference to the Figure the range R is given by the expression

$$R = h \cot \theta \tag{4}$$

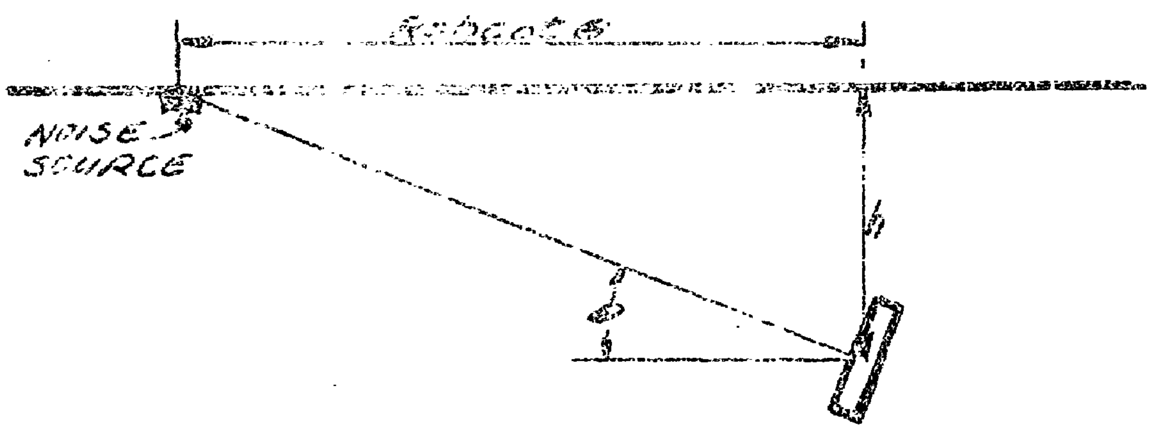


Figure 17

SECRET

D. Listening PPI

45. If a horizontally split projector is used with SSI, the scan is from the top to the bottom of the beam or vice versa as desired. Suppose that such a projector is employed, that it is stabilized against roll and pitch of the ship, and that it is elevated through an angle of 45°. Such a projector is shown mounted on the top side of a submarine in Figure 18. A beam

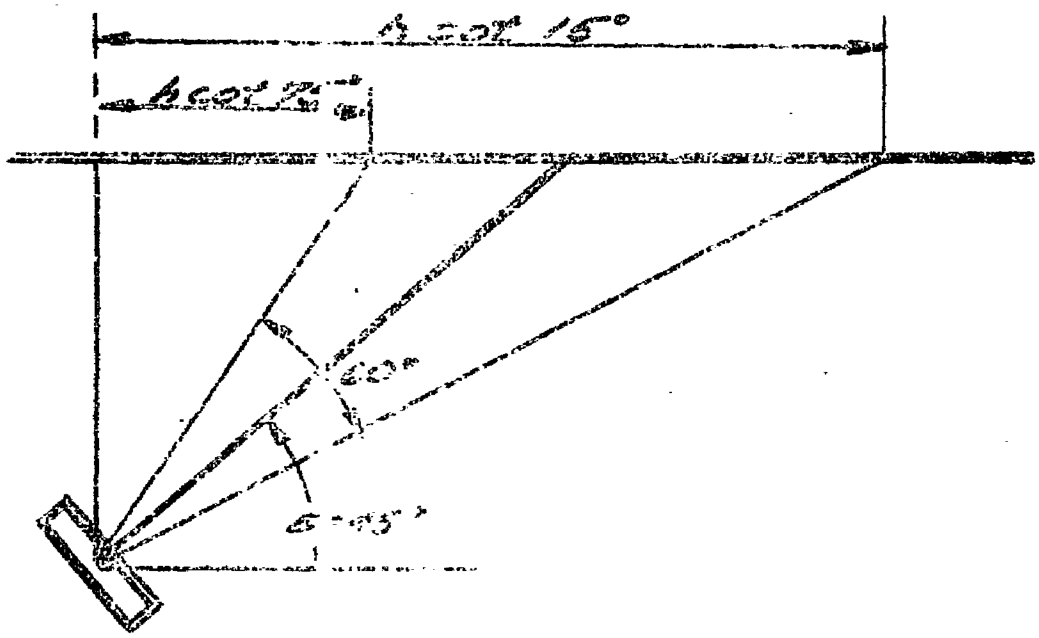


Figure 18

width of 60° is shown, and the scan is therefore from 15° elevation to 75° elevation. This scan in angle may also be regarded as a scan along the surface from a horizontal range h cot 15° to h cot 75°. Any noise source in the particular azimuth in which the projector is trained can give an indication on the screen dependent for its position upon the range of the source. In the listening PPI the horizontal sweep of Figure 1-b is replaced by a radial sweep from the edge of the screen nearly to the center. This radial line is so directed as to represent the relative bearing of the projector. The display when noise is picked up, is then as shown in Figure 19 with the relative bearing, B_r and approximately the range R indicated.

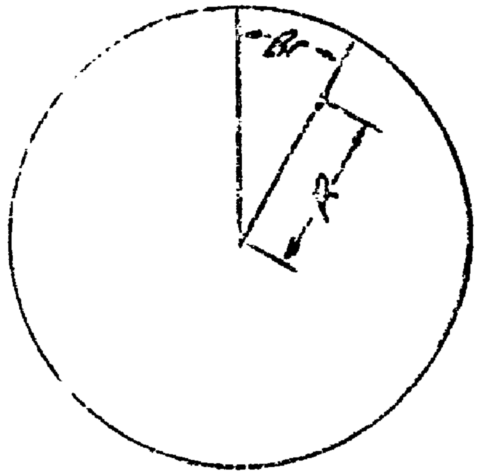


Figure 19

46. The orientation of the radial line on the screen follows the orientation of the projector automatically by means of a synchro-servo system. In use, the projector is intended to be rotated several times per minute and the display will thus include in their correct relative positions all noise sources swept through. The persistence of the screen is made long enough so that images from two successive sweeps appear simultaneously, thereby giving an indication of motions of the various targets. Figure 20 is the type of display obtained when sweeping is being

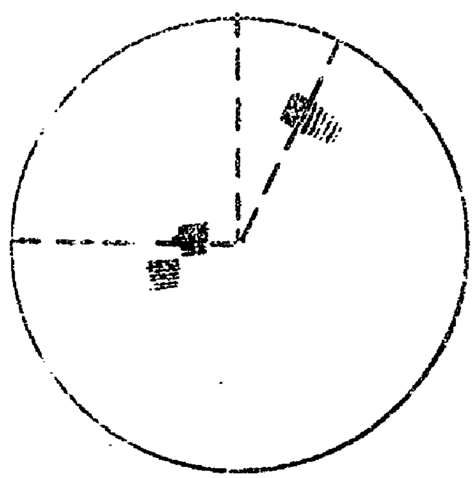


Figure 20

carried out. In this illustration two noise sources, the stationary one on bearing 030, and the moving one on bearing 270, are illustrated. The two images on about 270° are from two successive rotations through this noise source.

47. This listening PPI, which requires no transmission of signal is regarded as a defense weapon against attacking surface vessels. It should present valuable information to assist the captain in planning escape tactics. The possibility of firing torpedoes by means of listening SSI exists, but appears remote.

E. Aid in Echo Ranging

48. While ranges by triangulation are being sought, it does not seem propitious to do away with echo ranging. Rather, echo ranging should be confined to a few single pings, possibly with pulses so short that they possess no tonal quality. In some cases, particularly with short pings, the echo is badly masked by prop noise and its detection is difficult. To alleviate this unfavorable condition the sound operator may train behind the props by an amount which places them at or near a null point in the reception beam pattern, and may then echo range from the target's wake. As an aid in translating the range of the wake into the range of the target, the constants of SSI may be chosen such that when the props are on a null point the extension in range of the wake echo subtracted from the mean range of the wake echo will give the range of the target's props. In operation the operator of the range recorder could call out wake range and the operator of the SSI could call out an extension in range which is to be subtracted. The TDC operator could perform the subtraction mentally and check his problem setup. The geometry of the situation is shown in Figure 21. T is the target

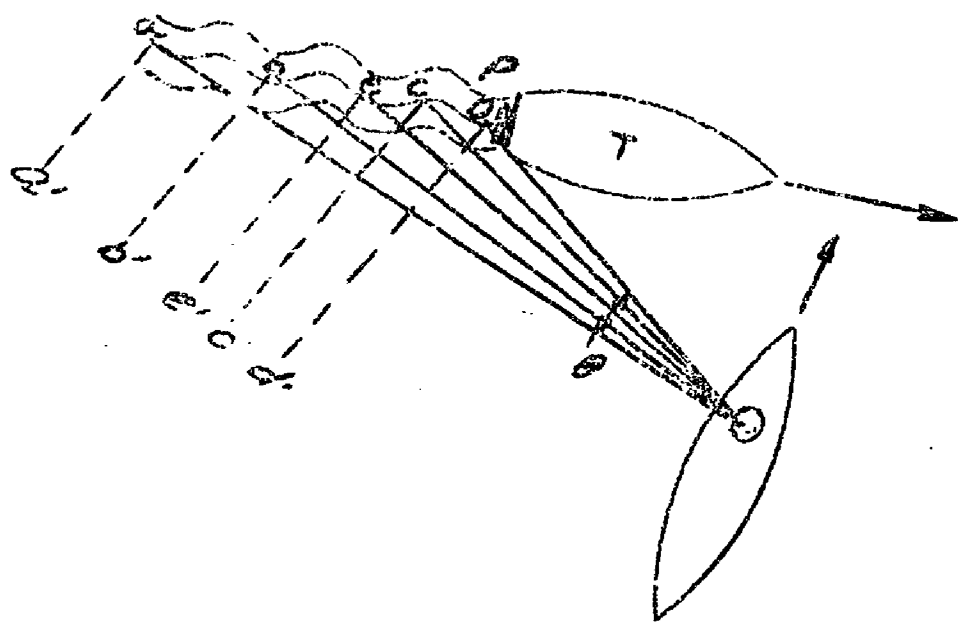


Figure 21

SECRET

ship the propellers (P) of which are kept centered on the SSI when not echo ranging. When echo ranging, the beam pattern of the projector is within the angle θ with null points in the directions oa and od. ob and oc are the limits of the SSI scan and oe is the projector axis. Making the angle eod equal to the angle boc, the extension in range shown on the SSI screen, namely b_1c_1 will be substantially identical with the extension in range of e_1d_1 and therefore may be subtracted from the mean wake range to give propeller range oP.

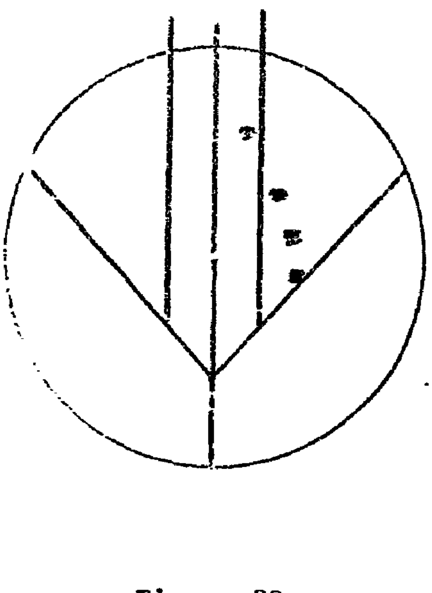
IV. USES IN NAVIGATION

A. Application to Small Object Location

50. At times, such as when running through a mine field, it is desirable to locate small objects. Various methods have been developed to all of which SSI in a particular form may be added with advantage. All such small object locaters must operate from echoes since the objects are not obliging enough to emit noise; consequently in the usual SSI display an indication like that of Figure 1-a would be obtained. Better visualization of the situation is to be anticipated if this type of scan is somewhat modified. The sound beam itself is shaped in the form of a sector of a circle of expanding radius. If the display of SSI is given the identical shape, the images of objects in the field will be shown correctly positioned relative to some reference line such as a vertical line on the screen indicating dead ahead. Any suitable scale may be chosen.

51. If the locater includes a searchlight beam which covers a relatively small angle it may be desired to rotate this projector continuously or in steps. In either case, the SSI display may be rotated in synchronism. If such rotation is zero, the apex of the display sector may most conveniently be placed near the bottom of the c-r tube. If rotation is through an angle of about ±60°, the center of rotation on the screen may preferably be placed somewhat below the center of the screen. If rotation is through 360°, the center of rotation should be placed at the center of the screen. All of these arrangements are attainable.

52. Figure 22 shows successive indications of a small object ahead of a submarine and to starboard. In order to obtain the



SECRET

Figure 22

latter indications it was necessary to rotate the projector and with it the display. It will be seen that when first detected the small object lay very close to the track of the submarine. Full left rudder was called and the indication veered to the right until it was at a safe distance from the track, at which time the submarine returned to zero rudder.

B. Use in Determining Bottom Contours

53. Indications of bottom slope are obtainable much in the same manner as target aspect, or wake aspect. For this purpose, the projector must be split horizontally and the indication shows deviation from the beam axis in a vertical plane. The display of Figure 2 (page 6) should be rotated downward the same amount as the projector is tilted downward. A gated vertical sweep should be employed for correct aspect indication (see II-D). With this arrangement the slope of that portion of the bottom on which the sound beam is trained is correctly displayed.

54. A typical display of the bottom is illustrated in Figure 23.

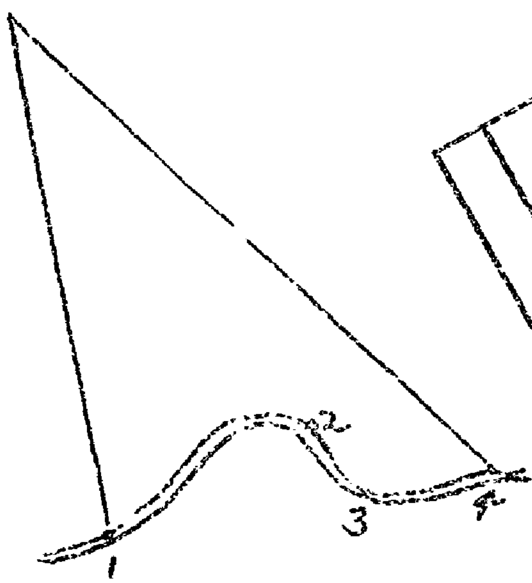


Figure 23-a

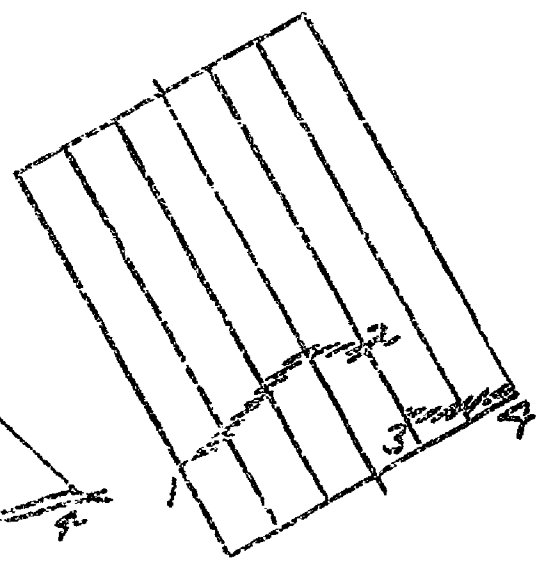


Figure 23-b

At 23-a, the vertical section through the bottom in the plane of which scanning is taking place is shown, together with the direction from which the sound wave impinges. At 23-b, the display obtained from the echo is given. (The slope of the bottom as indicated is independent of the tilt of the projector.) Points 1, 2, 3, and 4 in Figure 23-a are represented by corresponding points 1, 2, 3, and 4 in the image at 23-b. Note the absence of an echo between points 2 and 3 in the shadow zone.

SECRET

C. Use in Locating Temperature Layers.

55. Any temperature layer which is abrupt enough to give a good echo can be shown in aspect by the same method used for determining the slope of the bottom. While at the present time it is not known whether at some higher frequency good echoes can always be obtained from temperature layers, such a possibility is being investigated. If this should prove to be the case, the mapping of temperature layers might be of great help to a submarine if it is later under attack, and conversely to a surface ship attacking.

SECRET

APPENDIX A: SSI THEORY

I. SSI OPERATION

A. Dependence on Incoming Signals

1. SSI requires the use of a projector divided electrically into two parts with their centers of area displaced in the plane of scan. For the purpose of this discussion it will be assumed that the plane of scan is horizontal, and that the division is into two halves separated by the vertical diameter of the projector. When a noise or echo comes from the beam axis of the projector, the two halves of the projector respond exactly alike. If, however, the signal is displaced to the right of the beam axis, it reaches the right half of the projector before it reaches the left half giving rise to a phase lead in the right-half response ahead of the left-half response. SSI uses this phase difference in the two halves of the projector to produce an indication of the deviation of the source or reflector to the right or the left of the beam axis.

B. Block Diagram

2. Plate 1 is a block diagram of the equipment. There are two amplifying channels, one for the right half of the projector (shown across the top of the plate), the other for the left half of the projector (shown across the bottom of the plate). These amplifiers are of the superheterodyne type with separate local oscillators tuned to slightly different frequencies as shown. By heterodyning the two local oscillators against each other in a mixer, a 400-cycle/sec. difference frequency is obtained, which is passed through the second horizontal line of components in the diagram to synchronize a saw-tooth generator and thereby to provide a horizontal sweep across the screen of the cathode-ray tube. The third horizontal line of components represents the means for obtaining a vertical sweep.

3. The two amplifier channels are combined at the extreme right of the diagram to provide voltage for spot brightening at the proper position in each horizontal sweep when an echo or propeller noise is being received.

SECRET

C. Scanning the Screen

4. In the absence of an echo, the screen of the cathode-ray tube is normally dark. If, however, the intensity grid voltage is increased by turning the brightness control, an electron beam is permitted to strike the screen, thereby producing a fluorescent spot. This spot sweeps across the screen rapidly from left to right and then repeats to form a succession of horizontal lines. At the same time a slower vertical sweep deflects successive lines upward from the bottom to the top of the screen in such a manner that a rectangular area is covered, as in television, but at a much slower rate.

D. Vertical Sweep

5. The vertical sweep is produced by a saw-tooth current applied to the vertical deflection coils. This current is so synchronized with the transmission of sound into the water that the horizontal lines are deflected to the bottom of the screen at the instant of sound transmission, and thereafter progress upward. Vertical displacement from the bottom is therefore proportional to range. The range proportionality constant may be chosen by the operator to make the top of the screen correspond to any desired range, as for example, 3750 yards, 1500 yards, or 750 yards. If the transmitted pulse is initiated by a range recorder, the downward fly-back may be synchronized regardless of how far toward the top of the screen the vertical deflection has proceeded. When listening to noise the fly-back from the top to the bottom of the screen is accomplished automatically without external synchronization. A convenient time for the vertical sweep in this latter case is 6 seconds.

E. Reference System

6. The heart of the SSI is the means for synchronizing the horizontal sweep with spot brightening. To this end, a time reference system is employed. The two local oscillators of the SSI are tuned 400 cycles/sec. apart. The phase relations between the two oscillations may be shown on a clock diagram, as in Figure 24, in which a single hand rotating at 400 revolutions per second indicates at every instant the phase of the higher frequency relative to the lower.

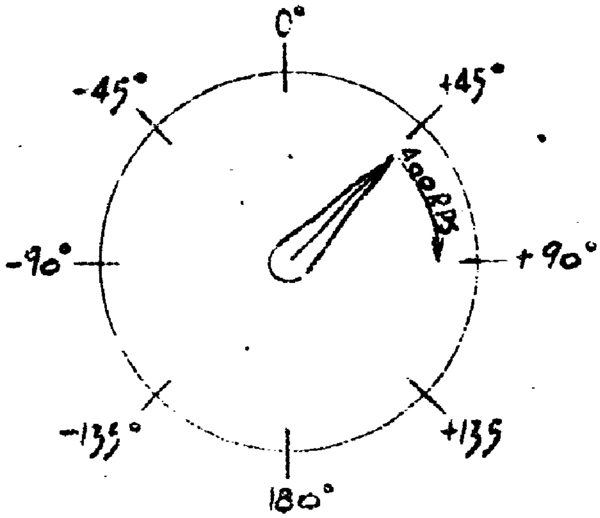


Figure 24

F. Horizontal Sweep

7. If the clock scale is broken at 180° and straightened, as in Figure 25, it represents the synchronism of the horizontal sweep, across the screen of the cathode-ray tube, with the phase relations between the two oscillations. This synchronism is

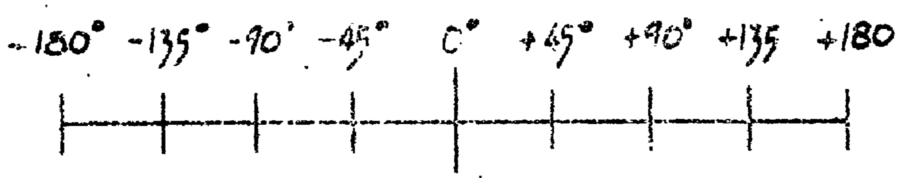


Figure 25

achieved as follows. The two local oscillations are heterodyned against each other to give a 400 cycle/sec. difference frequency. This difference frequency in the plate circuit of the mixer bears the definite relationship to the clock diagram of going through maximum when the clock hand goes through 180°. The voltage at the difference frequency is shifted in phase a fixed amount and distorted in the desired manner to trigger a gas tube, thereby discharging a condenser, whenever the clock hand goes through 180°. This discharge is used to make the sweep "fly back" from extreme right to extreme left at 180° (see Figure 25). Then, as the condenser charges, the spot sweeps across the screen in one revolution of the clock hand.

G. Synchronization of Signal

8. The signal from the right half of the projector is fed into the channel with the oscillator of higher frequency. In the superheterodyne mixer, phases (as well as frequencies) are subtracted. Thus, if the two incoming signals (right and left) are in phase, the two intermediate frequencies have relative phase identical with that of the local oscillations shown in Figure 24. By producing spot brightening when the two I.F.'s pass through phase coincidence (0° in Figure 24) the brightened spot falls on center (Figure 25), as it should for this case.

9. Suppose the signal output of the right half of the projector leads by 90° because the signal has a bearing deviation to the right. Then, because of subtraction of phases in the mixers, the I.F.'s have a relative phase retarded 90° from Figure 24, as shown by the added shorter hand in the clock diagram of Figure 26. This

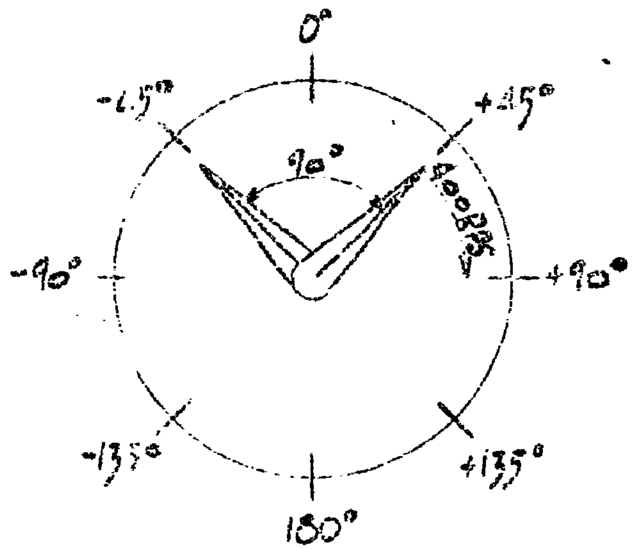


Figure 26

added hand is an I.F. relative-phase hand and rotates with a constant 90° lag behind the oscillation relative-phase hand for this example. Whenever the I.F. relative-phase hand passes through zero, spot brightening takes place. At such instants the oscillation hand is at $+90^\circ$; hence the brightened spot occurs at $+90^\circ$ on the sweep scale of Figure 25. In general, if the right half leads or lags the left by an angle not exceeding 180°, spot brightening occurs at the scale position of Figure 25 marking the lead or lag.

SECRET

H. Spot Brightening

10. The output of each I.F. amplifier is limited by driving grids of amplifiers below cutoff, thereby producing so-called "square" waves. These square waves, still at intermediate frequencies, are differentiated to produce sharp voltage pips. The voltage pips in the two channels, still at intermediate frequencies, are added together to produce extra high pips when they occur at the same time, as they do at phase coincidence once every 1/400th second. Only these high pips break through an amplifier biased below cutoff (clipper tube), and after proper filtering and inverting, become the voltage which is applied to the intensity grid of the cathode-ray tube to brighten the spot.

II. TUNABLE SSI

A. Advantages of Tunable SSI

11. The reasons for tuning any echo ranging gear are:

a. The choice of that operating frequency where the overall sensitivity of the echo ranging equipment is optimum.

b. The choice of that operating frequency where interference from echo ranging gears on the same or
or ships is minimized.

c. Variation in beam width, higher frequency giving a sharper beam when the same projector is used.

With SSI the reasons for tuning are the same with the addition of:

d. Selection of desired deflection sensitivity. This sensitivity increases with increase of frequency.

12. The advantages of a uni-control system of tuning the driver and receiver together are well known. If this system is employed it is obvious that the same advantages would become even greater if the SSI were included in the uni-control system.

SECRET

B. The Problem of Tuning SSI

13. The problem of tuning SSI is one of aligning two local oscillators 400 cycles apart ± 20 cycles over the frequency range and at the same time aligning with these local oscillators any tuned signal-frequency circuits which may be required. The alignment of the signal-frequency tuned circuits with each other must be a phase alignment which is considerably more critical than an amplitude alignment because at the peak response frequency the amplitude variation with frequency is zero while the phase variation with frequency is maximum. It is necessary then, that the signal-frequency tuned circuits be aligned with each other very carefully: their alignment with the local oscillators is not quite so important since if all are out of alignment with the local oscillators by the same amount the only effect is a decrease in sensitivity without relative phase shift between the two channels. The principle problems boil down to these two:

a. Tracking of the two local oscillators 400 cycles apart ± 20 cycles, and

b. Tracking of all tuned signal-frequency circuits with each other.

14. The following methods offer promise of providing tunability:

a. The difference frequency between the two local oscillators, already available, is put into a discriminator tuned to 400 cycles per second. This discriminator gives a d-c output which is positive or negative depending on the direction of deviation of the difference frequency from 400 cycles per second. The discriminator output is injected on the grid of a reactance tube used in the tuned circuit of one of the local oscillators and affecting its frequency of oscillation. The circuit is so arranged that variation in grid potential of the reactance tube tunes the oscillator of which it is a part, in the direction which makes the difference frequency between the two local oscillators approach 400 cycles per second. Ganged with the oscillator tuning condensers are those for signal-frequency tuning. Results to date indicate that some tuning ahead of the mixer in each channel is required. Either a single tuned circuit with a fairly high Q, or two tuned circuits in cascade each having a low Q appear to be satisfactory. Whatever circuits have to be tuned may have their condensers ganged with the oscillator

SECRET

tuning condensers. It should be noted that with this scheme misalignment of the signal frequency tuned circuits with the local oscillator tuned corcuits may not be serious since it results only in decreased sensitivity and not in relative phase shift between the two channels.

b. Another method of tuning is to use three oscillators, two on fixed frequencies 400 cycles per second apart, and the third tunable with its condenser tracked with the signal frequency tuned circuits. The variable frequency oscillation is heterodyned against each of the two fixed frequency oscillations to produce the variable frequencies, 400 cycles per second apart, which take the place of the local oscillations in the superheterodyne channel. These variable frequencies have to be carefully filtered.

c. A method of partial tuning involves the use of pairs of crystals to control the local oscillator frequency with the signal frequency stages tunable by means of ganged condensers. When it is desired to change frequency the pair of crystals in use is removed and a new pair is plugged in whereupon the signal frequency condensers may be retuned, for maximum response.

APPENDIX B: EXPERIMENTAL RESULTS TO DATE IN A/S WARFARE

A. Installation in USS FOSS

1. The potentialities of SSI in A/S warfare have been partially demonstrated in the Integrated Sonar type A installation in the destroyer escort USS FOSS. This installation was completed in February 1945 and tests are still continuing. The portions of the installation associated with the two SSI's are a projector, trainable, tiltable beyond 90°, and stabilized against roll and pitch of the ship, a coupler unit, and a pulse length control.

2. The projector is of the QB type - Rochelle salt crystals. It has a broad frequency-response characteristic peaking at 25 kilocycles/sec. It is split, electrically only, along vertical and horizontal diameters into quadrants. A three-axis system of stabilization keeps the splits horizontal and vertical despite rolling and pitching, while maintaining the bearing and depression called for. The training and tilting of the projector are independently controlled by two sound operators, but only the training operator is needed for searching.

3. The coupler unit eliminates the keying relay, an important function, but necessary with SSI only for extremely short ranges. More important for SSI operation, this unit combines the quadrants in various combinations and provides outputs of right and left halves, of top and bottom halves, and of the whole projector. The first and second pairs of outputs are fed to the two SSI units, the last to the receiver, which provides audible output and feeds the tactical recorder.

4. The pulse length control is mentioned here because results indicate that pulse length is of importance in obtaining the most information from the SSI. Pulse lengths of 2, 5, 10, 20, and 50 milliseconds are selectable.

5. One SSI, the display of which is on the console of the train operator, utilizes the pair of coupler unit outputs equivalent to right and left halves of the projector. This unit scans the primary reception lobe of the projector horizontally, and thereby shows the objects contained in the lobe in plan. The second SSI, the display of which is on the console of the tilt operator, utilizes the pair of coupler unit outputs equivalent to top and bottom halves of the projector. This second unit scans the primary reception lobe of the projector vertically, and thereby shows the objects contained in the lobe in elevation.

B. Operation of FOSS Equipment

6. In search, one operator seated at the train console (Figure 4, page 9) trains through the designated search sector on successive pings until contact is established. Contact may first be recognized aurally or on the chemical recorder, but should be readily identifiable on the SSI at about the same time. The position of the brightened spot in the horizontal scan on the cathode-ray tube indicates at once which way and how far the operator should train to center the target, and enables him continuously to maintain contact as long as echoes can be received.

7. Contact having been established, the tilt operator takes his position at the tilt console (Figure 4) for the attack. His SSI presentation shows the target on or off center vertically. In the approach, as the brightened spot moves down on the screen, he controls the tilt of the projector to bring it back to center. At close range he may anticipate the shift in position and, by tilting through possibly as much as a degree, or more, between two successive pings, keep the indication on center.

C. Operational Results

8. Experimental operation of the FOSS installation indicates that once a contact is made, operators with no special training in the use of this particular equipment can hold contact even when running directly over the target at 20 knots. Two runs in which the maximum tilt angles were 23° and 70° respectively are shown in the accompanying reproduction of recorder traces (Plate 2). The data regarding tilt is written on the traces along with an indication of minimum range. Perhaps the most striking demonstration occurred when working with the USS R-1 which had been modified to permit running at 13 knots submerged. With the R-1 maneuvering at will, the FOSS never lost contact during a 90-minute operating period.

9. One objective with the FOSS installation was to obtain depth of a submarine by measurement of the tilt angle and slant range. Several runs were made on a single day of operation with the submarine at depths of 100 feet, 200 feet, and 400 feet. Without the tilt operator's taking any particular care to keep the image centered and without his signalling when he was on the target, periodic observations of range and tilt were taken on the bridge repeater for the three submarine depths during approaches. From the data, depths were computed and these are plotted as curves (a), (b), and (c) of Plate 3 for the 100-foot, 200-foot, and 400-foot depths, respectively. The target was an Italian submarine which expresses its depth as distance of its water line below the surface. The limit

lines in the plate represent conning tower and keel on the assumption that the submarine was at the requested depth in each case.

10. Several conclusions can be drawn from these graphs of depth versus slant range, as follows:

a. Errors in individual determinations are rather large.

b. The depth indicated by an average of several determinations is reasonably good and is consistent out to the maximum range at which readings were taken.

To these conclusions may be added that some interference from surface-reflected echoes was observable at tilt angles of less than 6° or 7°, and less reliance was put on determinations at such angles although the graphs do not show less consistency at the longer than at the shorter ranges.

11. It was observed during operations in the FOSS that a good idea of target aspect was obtained from the SSI presentation when using short pulses (10 milliseconds or less). Admittedly, the Doppler effect is lost at the shorter pulse lengths, thereby giving less discrimination between echo and reverberations. This sacrifice may not be tolerable with poor water conditions. Even so, possibly one ping in four could be a short pulse primarily for aspect indication.

12. In the FOSS installation considerable attention was given to the display of target aspect. With a submarine as a target running slowly at 400 feet depth, conditions which should have given rise to no wake, an indication of aspect was clearly obtainable. For example, in a quarter approach, target angle 135°, the display showed the successive line segments from bottom to top in the duration of the echo displaced more and more to the right. The observed extension in range agreed approximately with that of the submarine. As the range was closed and a beam aspect obtained, a display was obtained which spread in an irregular manner completely across the screen. Beyond this in the approach, the successive line segments became displaced more and more to the left at increasing range, indicating a target angle between 0° and 90°, and finally, in passing directly ahead of the target the line segments of the display were aligned vertically. (See Figure 14, page 22.)

13. In the FOSS installation the method of aspect measurement in which the scan commences at the time of transmission was tried and gave an accuracy within $\pm 5°$ for the target course except when

SECRET

a near beam aspect was presented when the errors increased to 10° or 20°. The limitations of this type of presentation were recognized and the delayed sweep method is soon to be tried.

14. Recently a Librascope type of attack director was installed in the FOSS and operated with the Integrated Sonar equipment. With this combination the attack director has been found capable of tilting the projector correctly in runs directly over the target, so that the tilt operator has little to do except to detect slight bearing deviations caused by errors in the problem setup. An example of such a run is shown in the reproduction of the recorder trace in Plate 4. In this particular case the operator did not touch the tilt control within 400 yards of the target. The attack director should be capable of doing well on training although the speed of train is much higher than that of tilt when passing over the target.

APPENDIX C: EXPERIMENTAL RESULTS TO DATE IN PRO-SUBMARINE APPLICATIONS

A. Preliminary Experimental Installations

1. Early in the war, improvements in the sonar equipment in submarines lagged behind those in sonar equipment for surface vessels out of all proportion to the need for such improvements in the two cases. Recognizing this situation, NRL proposed to Comsublant certain experimental installations of SSI and other devices for submarines. Comsublant was at all times highly cooperative and much of the earliest experimental work with SSI was carried out in submarines. Here, naturally, the stress is on indications from prop noise rather than from echoes.

2. Successive installations of SSI in the USS S-48, the USS S-20, and the USS BASHAW, demonstrated that prop noise could be located by this device at ranges at least as great as those which would permit aural detection with conventional equipment, and that accuracy of at least ± 1 degree in bearing was obtainable, the training systems employed being the limiting factors in accuracy determinations.

3. The BASHAW installation utilized the whole projector for one channel and half the projector for the other. The display obtained with this arrangement proved inferior to that with the more conventional method in that only the central portion of the screen was useful. The method was thereupon discarded.

4. In these preliminary experiments, no range sweep was employed, successive horizontal sweeps being at a constant vertical position. Having worked for some time without a range sweep, NRL is now particularly aware of its advantages.

B. Plans for Installation of SSI with Torpedo Data Computer Mark IV

5. Having been advised of the accuracy of SSI in preliminary tests, the Bureau of Ordnance included in the design of torpedo data computer, Mark IV, provision for

a. reception of projector bearing by synchro repeat-back from the projector shaft at 1 and 36 speeds;

b. generated projector bearing by the TDC at 1 and 36 speeds including parallax corrections and allowance for travel time of sound, for direct comparison with the actual projector on ring dials; and

c. incremental relative bearing output for training the projector except for corrections added differentially by the sound operator.

SECRET

6. BuOrd and NRL, jointly, planned the installation of TDC Mark IV and SSI together in an experimental submarine; These plans were presented to other bureaus and to Comsublant. Modifications of the S-20 were authorized and she was made available for the installation and tests during November and December 1944.

C. Installation and Tests of SSI-TDC in the S-20

7. The installation and tests of SSI-TDC in the S-20 are covered in NRL Sound Report No. 42 of January 10, 1945. The abstract of that report reads as follows:

> "The tests of the BDI-TDC combination in the USS S-20 were conducted jointly by the Bureau of Ordnance and NRL.
>
> "Preparations entailed removal of the S-20 port side torpedo stowage facilities, replacement of the sonar equipment by modern components, and the installation of: (a) a 4KVA MG set, (b) a split QB projector, (c) projector training gear similar to WFA type but driving a top-side mount with 36 speed control and 1 and 36 speed repeatbacks, (d) BDI, (e) TDC Mark IV Mod O, (f) BDI repeater, and (g) a periscope target-bearing repeater.
>
> "The tests included practice runs, a calibration run, runs for recording dial readings with the target on a known fixed course at known speed, and regular fox runs by the target ship with the submarine simulating attacks. In eight simulated attacks the S-20 used sound information exclusively while sound contact was maintained.
>
> "The calibration runs showed the difference between observed sound bearing (plus computed parallax bearing) and periscope bearing to be 12' on the average over the 40 readings on bearings all around the submarine except around the bow and conning tower.
>
> "During the simulated attacks, four torpedoes were fired; three were hits and the fourth was "cold"."

8. From these tests, and from others wherein TDC was used without SSI, it appears to many observers that the installation in the S-20 is the type best suited for operation with TDC. The situation is perhaps best summarized by quoting from a letter written by Comsublant to Chief of Naval Operations:

APPENDIX D: DESIGN OF PROJECTOR FOR SSI

A. Faults in Present Design

1. With the development of BDI there came the split projector which receives two signals which in general differ in phase, for feeding two channels. There seems to have been no design work carried out on the split projector beyond the decision to split a standard projector along a vertical diameter. The same simple construction has generally been used with SSI except in the FOSS installation, where vertical and horizontal splits into quadrants enabled combination of pairs of quadrants into right half, left half, top half, and bottom half. As a receiving projector, half a circle is poor because of the very wide beam pattern and the very high secondary lobes. Furthermore, the proportioning of the factors - transmitting beam widths, receiving beam widths, and angle scanned through - is particularly ill-chosen in this "design". The scan is within the limits of the transmitting beam pattern, and no echoes would be expected to be received at the edge of this beam because no energy is sent out in this direction. The receiving beam pattern, on the other hand, is only three or four decibels below peak response at the edge of the transmitting beam. Consequently, at reception, interfering noise can be picked up throughout a solid angle of several times the useful solid angle.

B. Necessity for Compromise

2. Projector design requires compromises between the following pairs of factors:

a. Narrow beam width and reduced minor lobes

b. Narrow receiving beam width and deflection sensitivity

c. Beam pattern in vertical plane and beam patterns in other planes.

There are methods of reducing the minor lobes 30 decibles or more below the main lobe. However, these methods cause a widening of the beam pattern which may lower the directivity index more than high minor lobes do. A good compromise is reached when the minor lobes are reduced a little over 20 decibels below the main lobe. Receiving beam width can be decreased by permitting the two sections of a split projector to overlap. This overlap closes the distance between the centers and thereby decreases the deflection sensitivity.

SECRET

However, in order to narrow the beam by some 30%, and to suppress the minor lobes to 20 db down some sacrifice in deflection sensitivity is worth-while, particularly since it can be restored by means of a phase difference expander. Experience has shown that interference, probably from surface reflected echoes, is most serious in the vertical plane. Consequently, the beam pattern in this plane should be sharper and should have suppressed minor lobes even if optimum design in other planes is thereby rendered impossible.

3. A proposed design of projector which appears to be the best compromise between the factors involved for SSI is shown in Plate 5. This is a four-section design capable of combination to give a right and left pair of sections and simultaneously a top and bottom pair of sections. The right and left sections are symmetrical relative to vertical axes through their centers: the top and bottom sections are symmetrical relative to horizontal axes through their centers.

4. Plate 6 shows the theoretical receiving beam pattern in a vertical plane of a projector split into halves and also that of the proposed design. The narrowing of the beam, and the reduction of the minor lobes in the latter may be noted.

SECRET

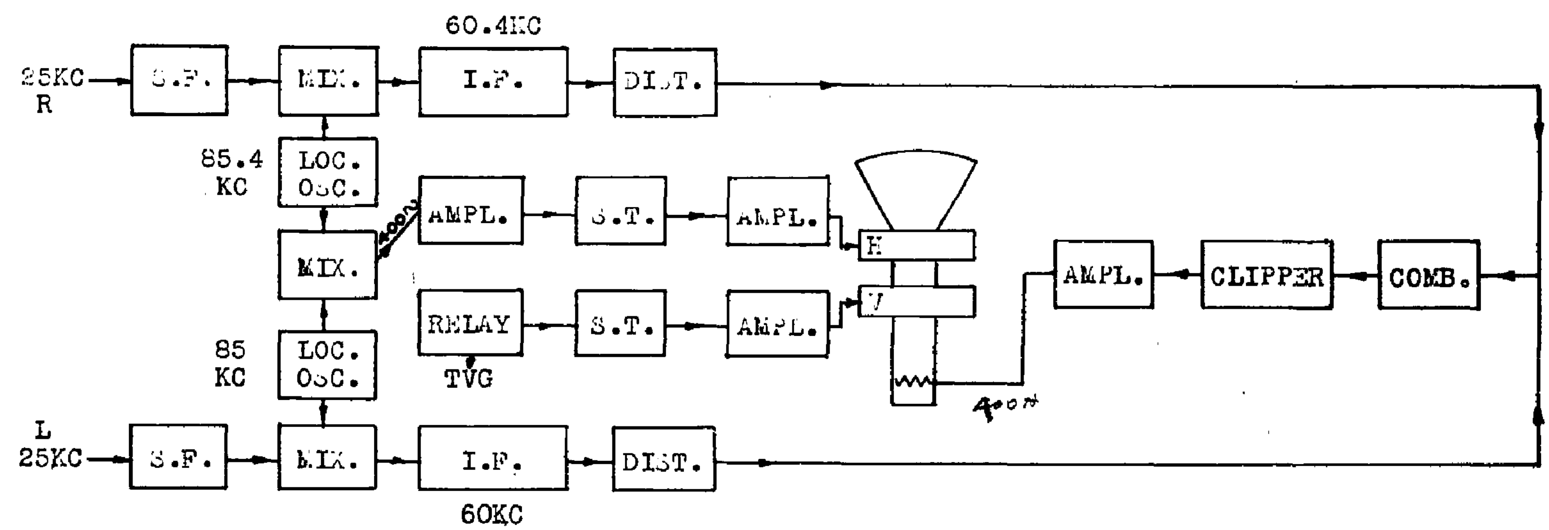
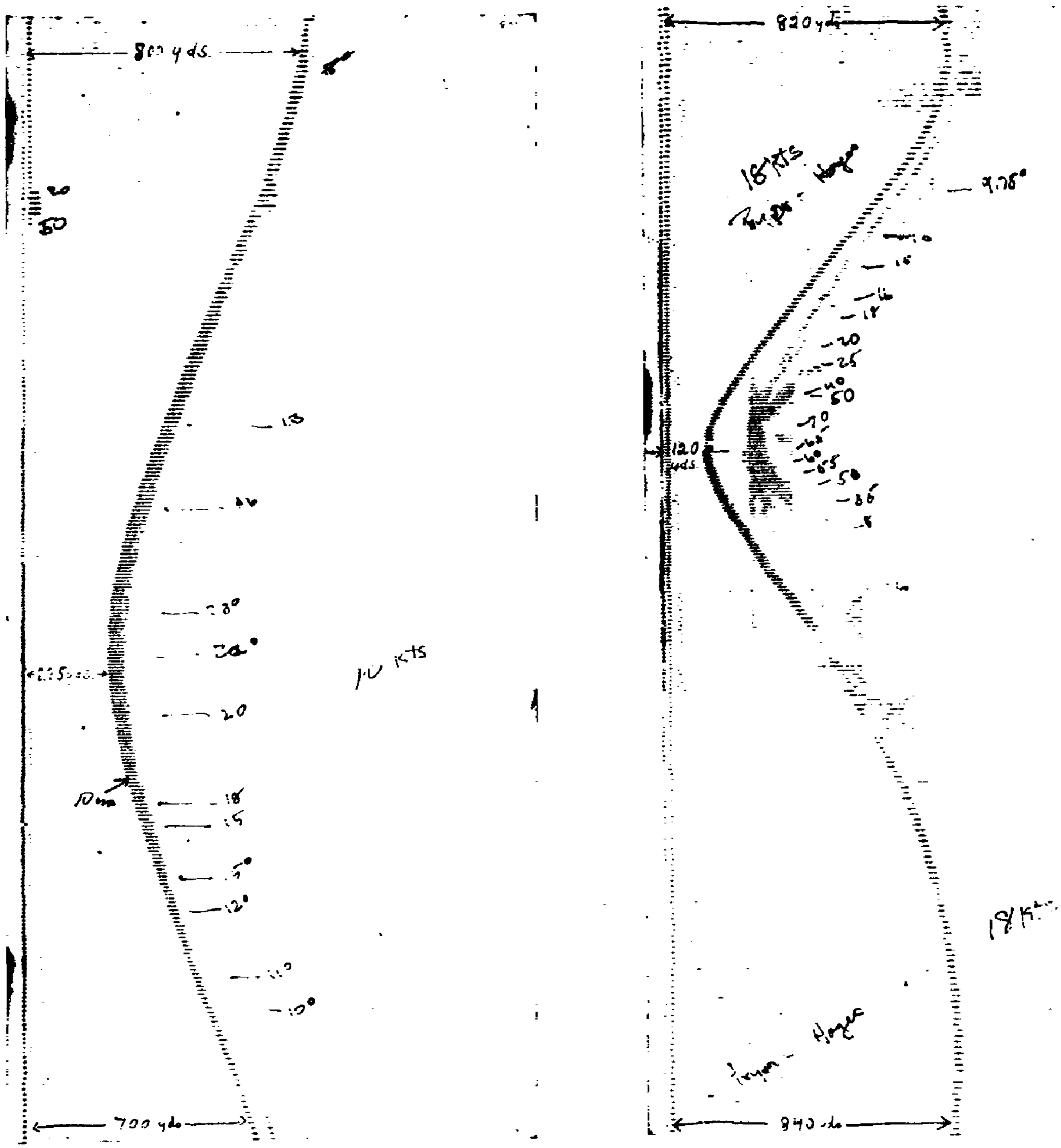


PLATE I

U. S. NAVAL RESEARCH LABORATORY WASHINGTON 20, D. C.	SCALE	BLOCK DIAGRAM OF	[redacted]
B'LD'G. / PHONE	DR'WN.		
ROOM / DATE	CH'K'D.		
	APPR'V'D.	UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE ±	474-A-6 -7

SHEET 1 OF 1



RECORDER TRACES - INTEGRATED SONAR
SUBMARINE SPEED 4 KTS.
D.E. SPEED 10 AND 18 KTS.
(TILT ANGLES SHOWN IN DEGREES AT RIGHT OF TRACE)
MARCH 16, 1945

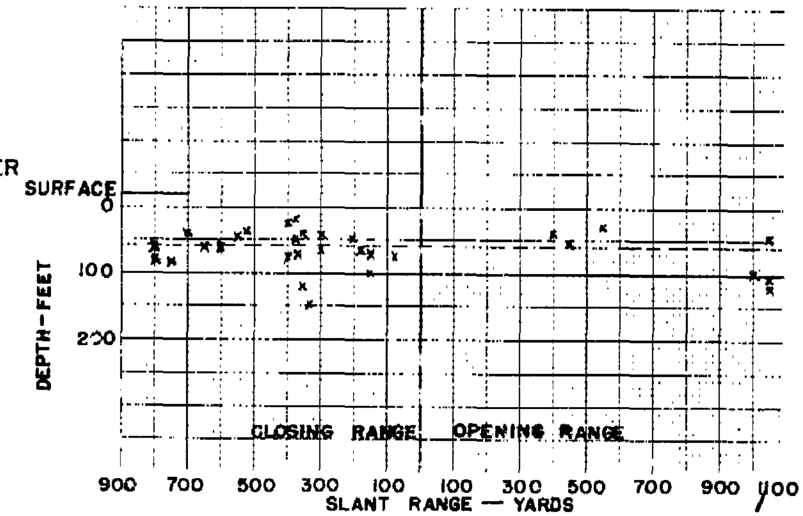
SUBMARINE DEPTH DETERMINATION
U.S.S. FOSS
MARCH 17, 1945

— TRUE KEEL DEPTH

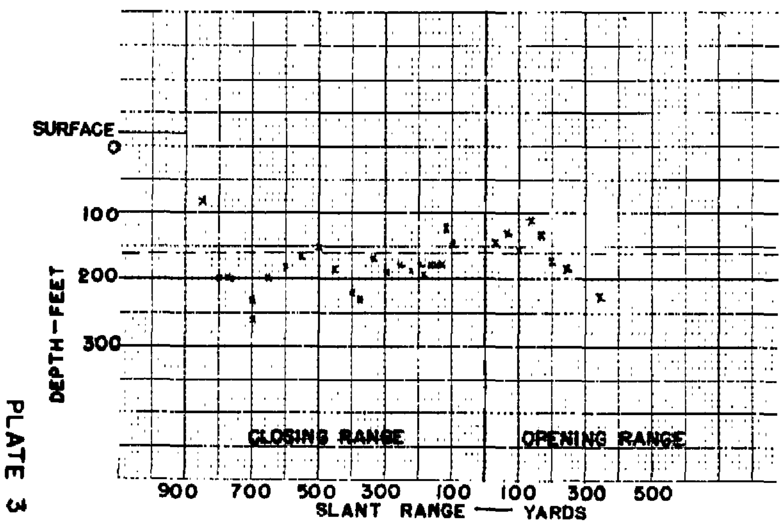
--- TRUE CONNING TOWER DEPTH

X = COMPUTED DEPTH

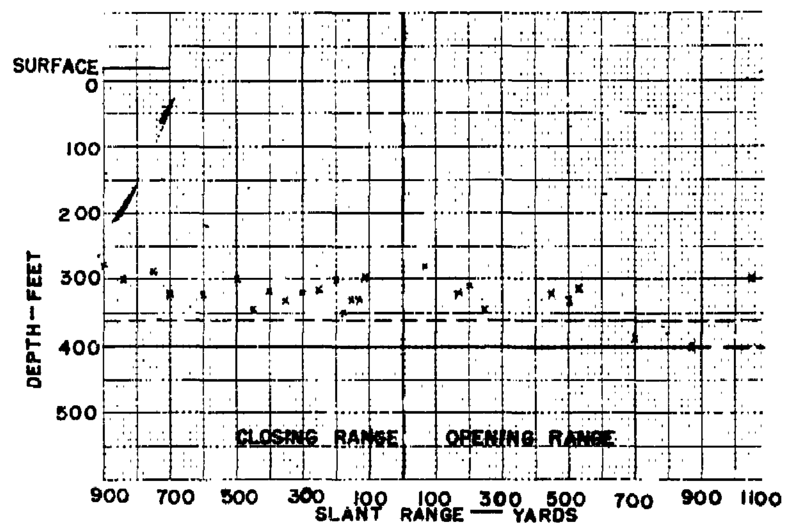
ZERO DEPTH = PROJECTOR DEPTH = 20 FEET



(A)



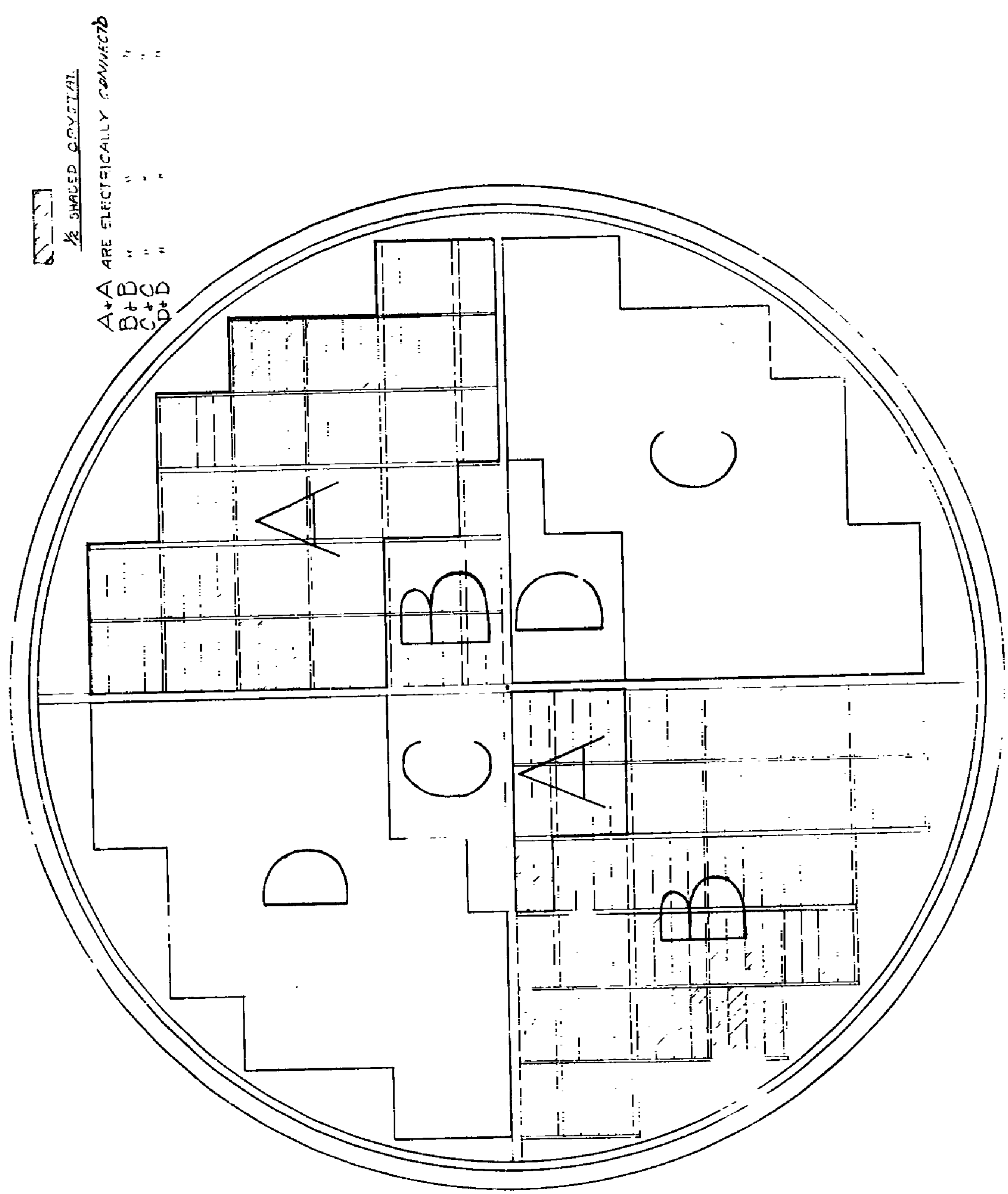
(B)



(C)

SECRET

PLATE 4



SECRET

PLATE 5

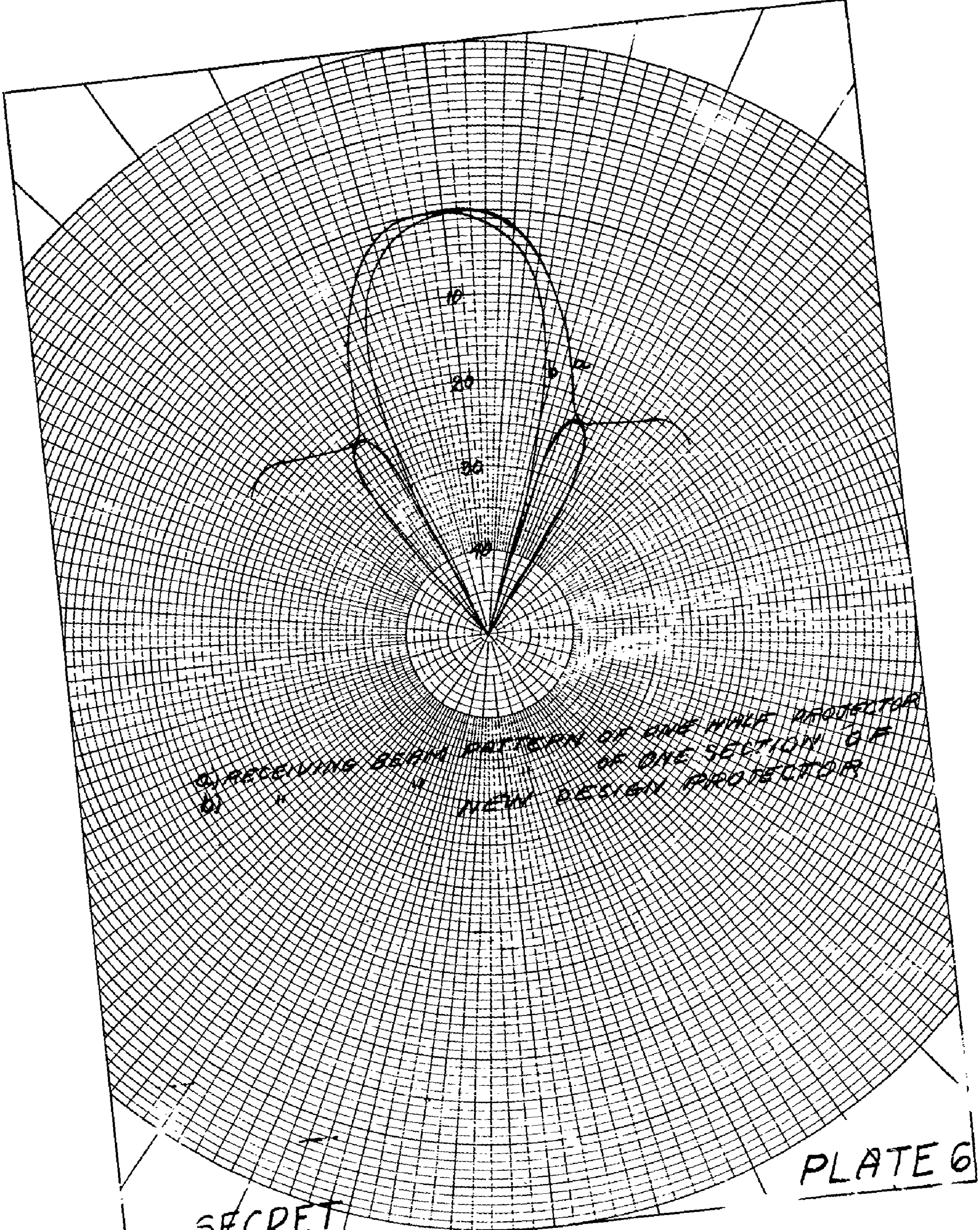


PLATE 6

SECRET

CONFIDENTIAL

CONFIDENTIAL

UNITED STATES GOVERNMENT

memorandum

7103/106

DATE: 30 September1996

FROM: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

TO: Code 1221.1

VIA: Code 7100

AD-310 377

REF: (a) NRL Confidential Report #S-2631 by H.L. Saxton, August 1945 (U)
(b) DoD Dir. 5200.9

1. Reference (a) is a report on the theory, development and testing of the Sector Scan Indicator, a SONAR instrument that displays the range and bearing of an acoustic return within the beam of a directive transducer.

2. The science and technology of this report is currently well known in underwater acoustics.

3. Reference (a) was declassified by reference (b).

4. Based on the above, it is recommended that reference (a) be released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
Acoustics Division

CONCUR:

Edward R Franchi 9/30/96

EDWARD R. FRANCHI Date
Superintendent
Acoustics Division

Completed
2-7-2000
R.W.

OPTIONAL FORM NO. 19
(REV). 1-80)
GSA FPMR(41 CFR) 101-11.6
5010-114